Water Quality of Camp Creek, Costello Creek, and Other Selected Streams on the South Side of Denali National Park and Preserve, Alaska

Water-Resources Investigations Report 02–4260

Prepared in cooperation with the
NATIONAL PARK SERVICE

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Cover photograph: View of Costello Creek with Camp Creek in foreground, June 1, 2000. Photograph by Tim Brabets, U.S. Geological Survey

Water Quality of Camp Creek, Costello Creek, and Other Selected Streams on the South Side of Denali National Park and Preserve, Alaska

By Timothy P. Brabets and Matthew S. Whitman

Water-Resources Investigations Report 02-4260

Prepared in cooperation with the National Park Service

U.S. DEPARTMENT OF THE INTERIOR

GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY

Charles G. Groat, Director

Anchorage, Alaska, 2002

For additional information write to:
Alaska Science Center
Chief, Office of Water Resources
U.S. Geological Survey
4230 University Drive, Suite 201
Anchorage, AK 99508-4664

For more information on the USGS in Alaska, you may connect to the Alaska Science Center Home Page at:
http://alaska.usgs.gov
For more information on all USGS reports and products (including maps, images, and computerized data), call 1-888-ASK-USGS

Water-Resources Investigations Report 02-4260

CONTENTS

Abstract 1
Introduction 1
  Purpose and Scope 4
  Acknowledgements 4
Description of Study Area 5
  Methods of Data Collection and Analysis 8
Water quality of Camp Creek, Costello Creek, and other selected streams 12
  Physical properties 12
    Streamflow and suspended sediment 12
    Specific conductance 12
    pH 15
    Water temperature 15
    Dissolved Oxygen 15
    Alkalinity 15
    Major ions and dissolved solids 15
  Nutrients and organic carbon 18
  Organic compounds 21
  Trace elements 23
Cluster and discriminant analysis of trace element data in bed sediments 29
Physical habitat and biology of Camp Creek and Costello Creek 33
  Physical habitat 33
  Invertebrates 33
  Algae 36
Summary and Conclusions 39
References Cited 40
Appendix 43

FIGURES

Figures 1-3. Maps showing:
  1. Location of Denali National Park and Preserve and the Cook Inlet Basin 2
  2. Shaded relief of the Susitna River Basin, south side of Denali National Park and Preserve, and sampling sites 3
  3. Camp Creek and Costello Creek watersheds 4
  4. Photograph of the Dunkle Mine looking southwest towards confluence of Camp Creek and Costello Creek 5
Figures 5-6. Maps showing:
  5. Locations and drainage basins of sampling sites in south side of Denali National Park and Preserve 6
  6. Geology of the south side of Denali National Park and Preserve 7
Figures 7-8. Photographs showing:
  7. Camp Creek 8
  8. Costello Creek 9
Figures 9-10. Diagrams showing:
  9. Trilinear diagram of water samples from Camp Creek and Costello Creek 19
  10. Trilinear diagrams of water samples collected at sites on the south side of Denali National Park and Preserve 20
  11. Dendograms of the cluster regions of sites with trace element bed sediment data 33
  12. Major geomorphic features of the Camp Creek study reach 34
  13. Major geomorphic features of the Costello Creek below Camp Creek study reach 35
  14. Invertebrate community metrics from Camp Creek and Costello Creek compared to national land-use values 37
  15. Relative abundance of diatoms at sampling sites for each species making up more than 10 percent of a sample 38
  16. Algal status index for Camp Creek and Costello Creek below Camp Creek 39

TABLES

1. Water-quality sites, south side of Denali National Park and Preserve, Alaska 10
2. Discharge, physical properties, and suspended sediment measured at Camp Creek at mouth near Colorado, Alaska 13
3. Discharge, physical properties, and suspended sediment measured at Costello Creek below Camp Creek near Colorado, Alaska 13
4. Ranges in streamflow and physical properties for water-quality sites on the south side of Denali National Park and Preserve, Alaska 14
5. Major dissolved inorganic constituents measured in water samples collected from Camp Creek at mouth near Colorado, Alaska 16
6. Major dissolved inorganic constituents measured in water samples collected from Costello Creek below Camp Creek near Colorado, Alaska 16
7. Ranges in concentrations of water-quality samples collected at sites located in the south side of Denali National Park and Preserve, Alaska 17
8. Results of regression analysis relating concentrations of dissolved solids and major ions to specific conductance in streamflow samples collected from streams, south side of Denali National Park and Preserve, Alaska 21
9. Nutrient and organic carbon concentrations measured in water samples collected from Camp Creek at mouth near Colorado, Alaska 22
10. Nutrient and organic carbon concentrations measured in water samples collected from Costello Creek below Camp Creek near Colorado, Alaska 22
11. Organic compounds analyzed for detection in bed sediments of Costello Creek above Camp Creek, Camp Creek, and Costello Creek below Camp Creek near Colorado, Alaska 23
12. Concentrations of organic compounds detected in bed sediments of Costello Creek above Camp Creek at mouth near Colorado, Alaska 23
13. Concentrations of organic compounds detected in bed sediments of Camp Creek near Colorado, Alaska 24
14. Concentrations of organic compounds detected in bed sediments of Costello Creek below Camp Creek near Colorado, Alaska 24
15. Trace element concentrations measured in water samples collected from Camp Creek at mouth near Colorado, Alaska 25
16. Trace element concentrations measured in water samples collected from Costello Creek below Camp Creek near Colorado, Alaska 26
17. Correlation coefficients for aluminum, iron, and suspended sediment for Camp Creek and Costello Creek below Camp Creek near Colorado, Alaska 27
18. Summary of dissolved trace element concentrations from previous studies compared to ranges of dissolved trace element concentrations from Camp Creek and Costello Creek near Colorado, Alaska 27
19. Dissolved concentrations of selected trace elements that have established water-quality standards for protection of aquatic life 28
20. Trace element concentrations measured in fish tissue samples collected from Costello Creek above Camp Creek, Camp Creek, and Costello Creek below Camp Creek 28
21. Trace element concentrations measured in bed sediment samples collected from sites on the south side of Denali National Park and Preserve 30
22. Concentrations of selected trace elements in bed material from various studies 32
23. Concentrations of trace elements, percent organic carbon, and mean PEC quotient for sites on south side of Denali National Park and Preserve, Alaska 32
24. Invertebrate community metrics 38
25. Metric values for algae samples 39
Appendix 1. Benthic macroinvertebrate data 44
Appendix 2. Periphytic algae data 48

CONVERSION FACTORS, WATER-QUALITY ABBREVIATIONS, AND VERTICAL DATUM

Multiply	by	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
ton	0.9072	megagram
Degree Fahrenheit	°F = 1.8 (°C) + 32	Degree Celsius

Chemical concentration and water temperature are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute mass per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter (µS/cm) at 25°C.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—A geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

ADDITIONAL ABBREVIATIONS

CCME - Canadian Council of Ministers for the Environment
DNPP - Denali National Park and Preserve
TEC - Threshold Effect Concentration
TEL - Threshold Effect Level
PEC - Probable Effect Concentration
PEL - Probable Effect Level
NAWQA - National Water-Quality Assessment

Water Quality of Camp Creek, Costello Creek, and Other Selected Streams on the South Side of Denali National Park and Preserve, Alaska

By Timothy P. Brabets and Matthew S. Whitman

ABSTRACT

The Camp and Costello Creek watersheds are located on the south side of Denali National Park and Preserve. The Dunkle Mine, an abandoned coal mine, is located near the mouth of Camp Creek. Due to concern about runoff from the mine and its possible effects on the water quality and aquatic habitat of Camp Creek and its receiving stream, Costello Creek, these two streams were studied during the summer runoff months (June to September) in 1999 and 2000 as part of a cooperative study with the National Park Service. Since the south side of Denali National Park and Preserve is part of the U.S. Geological Survey's National Water-Quality Assessment Cook Inlet Basin study unit, an additional part of this study included analysis of existing water-quality data at 23 sites located throughout the south side of Denali National Park and Preserve to compare with the water quality of Camp and Costello Creeks and to obtain a broader understanding of the water quality in this area of the Cook Inlet Basin.

Analysis of water column, bed sediment, fish, invertebrate, and algae data indicate no effects on the water quality of Camp Creek from the Dunkle Mine. Although several organic compounds were found in the streambed of Camp Creek, all concentrations were below recommended levels for aquatic life and most of the concentrations were below the minimum reporting level of 50 μg/kg. Trace element concentrations of arsenic, chromium, and nickel in the bed sediments of Camp Creek exceeded threshold effect concentrations (TEC), but concentrations of these trace elements were also exceeded in streambed sediments of Costello Creek above Camp Creek. Since the percent organic carbon in Camp Creek is relatively high, the toxicity quotient of 0.55 is only slightly above the threshold value of 0.5. Costello Creek has a relatively low organic carbon content and has a higher toxicity quotient of 1.19.

Analysis of the water-quality data for other streams located in the south side of Denali National Park and Preserve indicate similarities to Camp Creek and Costello Creek. Most of the streams are calcium bicarbonate/calcium bicarbonate-sulfate type water with the exception of two streams that are calcium sulfate and magnesium sulfate type water. Trace element concentrations of arsenic, chromium, and nickel in the bed sediments of 9 streams exceeded the TEC or the probable effect concentration (PEC). Seven streams exceeded the threshold value of the toxicity quotient. Analysis of trace element concentrations in bed sediment and basin characteristics for 16 watersheds by cluster and discriminant analysis techniques indicated that the watersheds could be separated into two groups based on their basin characteristics.

INTRODUCTION

Denali National Park and Preserve (DNPP), approximately 6 million acres in size, is located in central Alaska (fig. 1). The Alaska Range, dominated by Mt. McKinley, bisects the park. Rivers draining the north side of the Alaska Range, flow to the Tanana River or Kuskokwim River. The south slopes of the Alaska Range form the headwaters for water bodies that drain into the Susitna River (fig. 2), which flows into Cook Inlet.

Mining for gold, lead, zinc, silver, copper, antimony, and coal has occurred since 1906 at various locations within the current park boundary. Although the principle mining district was on the north side of DNPP, commercial discoveries of coal were made in the Dunkle Hills (fig. 2) on the south side of the park. Exploratory activities in the Dunkle Hills also yielded small quantities of gold and silver.

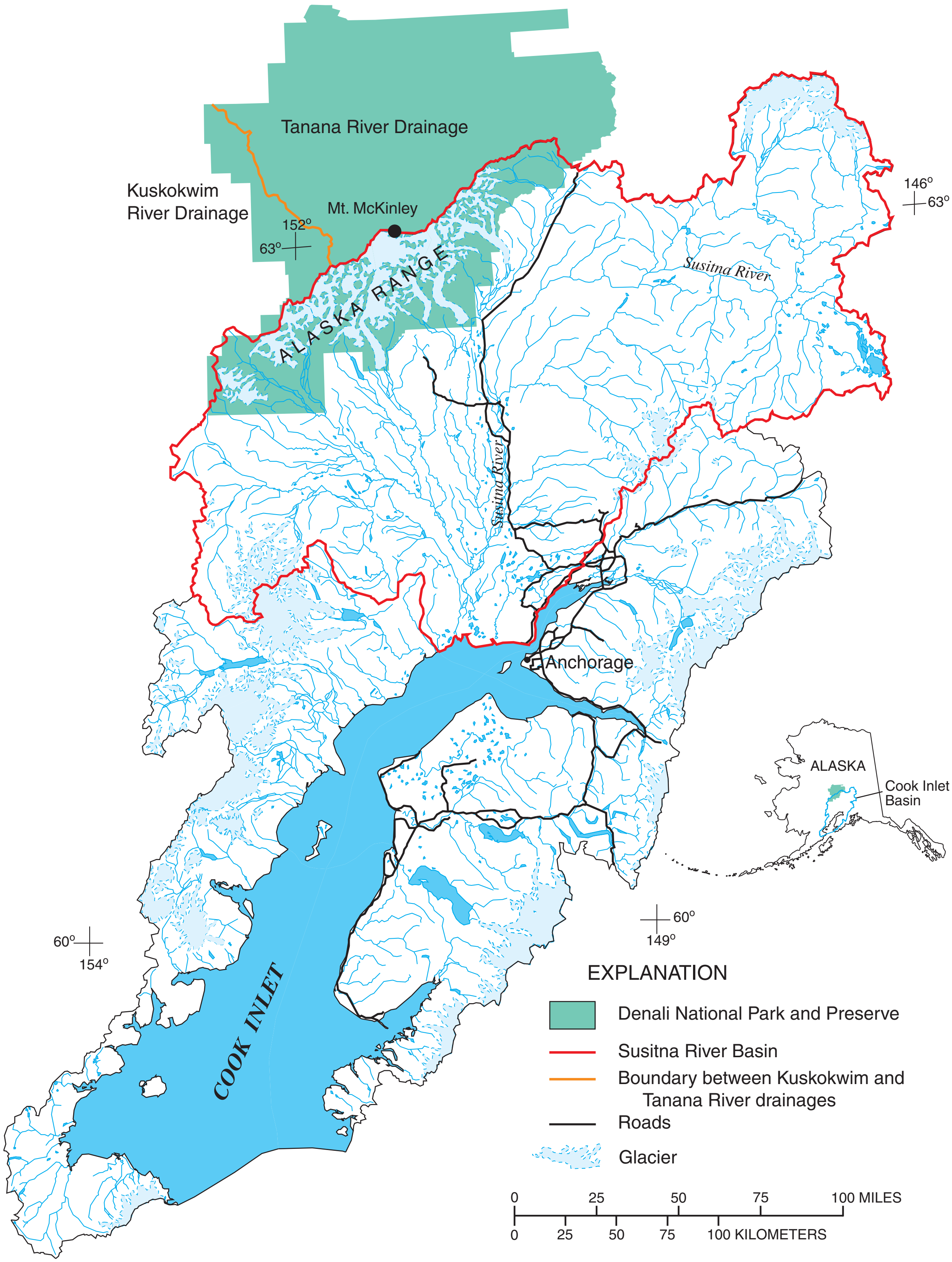

Figure 1. Location of Denali National Park and Preserve and the Cook Inlet Basin.

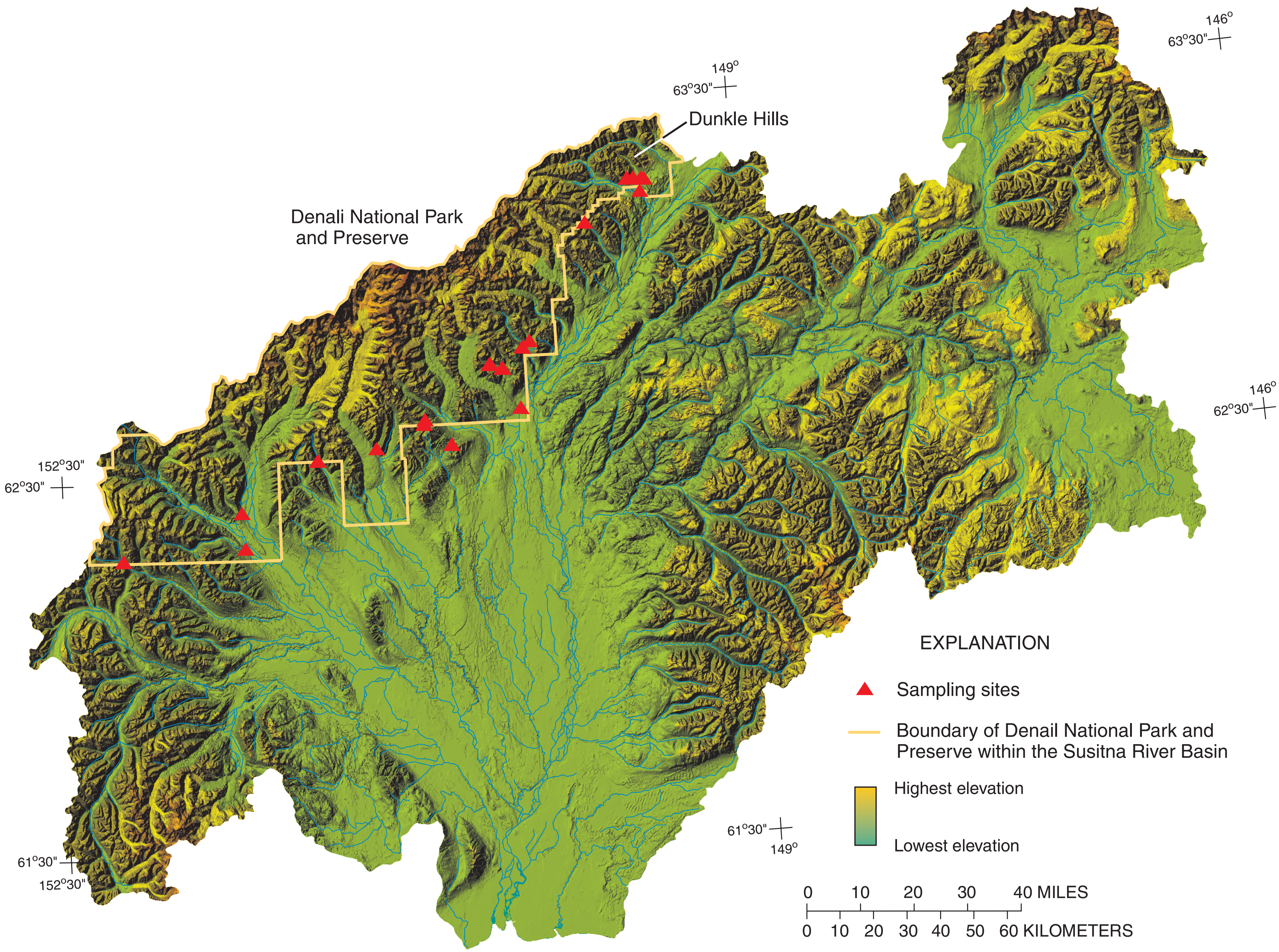

Figure 2. Shaded relief of the Susitna River Basin, south side of Denali National Park and Preserve, and sampling sites.

The Dunkle Mine is an abandoned lignite coal mine located at an altitude of 2,800 feet in the Camp Creek watershed (fig. 3). The mine was active primarily from 1940 to 1954 (National Park Service, 1983). Today, the mine site consists of a shallow excavation into the side of a hill. Exposed coal seams are visible, as well as piles of unharvested coal and overburden (fig. 4). Water enters the excavated area by means of runoff and seepage from the tundra upslope, drains into Camp Creek, and then Costello Creek (Dale and Stottlemyer, 1985). Costello Creek is fed primarily by meltwater from perennial snowfields crowning the south side of the Alaska Range above 5,000 feet (fig. 3).

No water-quality data had been collected at streams and rivers on the south side of DNPP until 1994. Edwards and Tranel (1998), conducted a parkwide inventory of water-quality data on 61 streams and rivers from 1994 to 1996. Several water-quality samples were collected from Costello Creek and Camp Creek and at 23 other sites located in the south side of DNPP (fig. 5). In 1998, as part of the U.S. Geological Survey's Cook Inlet Basin National Water-Quality Assessment (NAWQA) program, bed sediment and tissue (BST) survey, Costello Creek and Colorado Creek were studied (Frenzel and Dorava, 1999, Frenzel, 2000). A variety of water-quality and biological data were collected and analyzed from these two sites.

Purpose and Scope

This report summarizes the results of a cooperative study by the National Park Service (NPS) and the U.S. Geological Survey (USGS) to study the water quality of streams on the south side of DNPP. The purpose of this study was to: (1) determine if the Dunkle Mine has affected the water quality of Camp Creek and Costello Creek; (2) compare the water-quality data from Camp Creek and Costello Creek with other streams on the south side of DNPP, and (3) add to the existing water-quality data base of DNPP.

Acknowledgements

The author gratefully acknowledges the assistance of Ken Karle and Pam Sousanes of Denali National Park and Preserve in field work and for providing data from other sites in the study area. As part of the U.S. Geological Survey Volunteer for Science program, Cecile Kouzarides created the Geographical Information Systems data sets and computed basin characteristics for each watershed. Dan Hawkins, Professor Emeritus, University of Alaska, Fairbanks, assisted in the statistical analysis. Resources were also provided to the study from the U.S. Geological Survey National Water-Quality Assessment program, Cook Inlet Basin study unit.

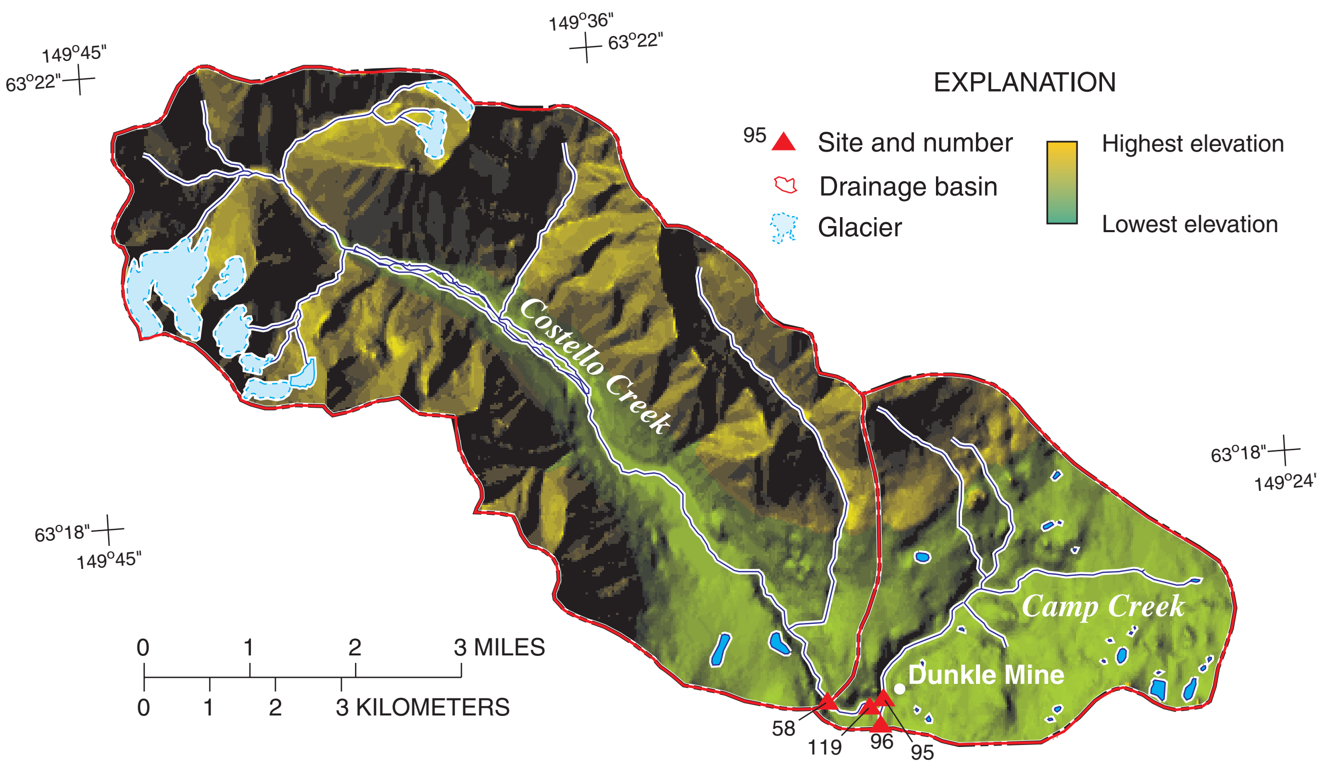

Figure 3. Camp Creek and Costello Creek watersheds.

Figure 4. Dunkle mine looking southwest towards confluence of Camp Creek and Costello Creek (Photo taken in 1975 by Andrew Kirsch, provided by Chuck Hawley).

DESCRIPTION OF STUDY AREA

The south side of DNPP lies in the Susitna River drainage on the southeastern flank of the central Alaska Range (fig. 2). Rounded aligned hills and U-shaped valleys that range from 2,000 to 3,000 feet in elevation are the result of extreme glacial scour during Late Wisconsin time 10,000 years ago. Approximately 33 percent of the south side of DNPP is covered by glaciers (fig. 6).

The geology of the study area (fig. 6) consists primarily of Quaternary Rocks (21 percent), Tertiary Rocks (12 percent), Cretaceous and/or Jurassic Sedimentary Rocks (23 percent), and Permian to Devonian Rocks (8 percent). Quaternary rocks are surficial deposits consisting of unconsolidated silt, sand, and gravel of fluvial, glacial, colluvial, and other origins. Tertiary rocks are of early Oligocene or late Ecoene age that consist of grandiorite and granitic rocks. Cretaceous and Jurassic rocks are dark-gray to black argillite, fine- to coarse-grained, generally dark-gray graywacke, dark-gray polymictic pebble conglomerate, a few layers of dark-gray to black radiolarian chert and thin, dark-gray impure limestone interbeds. Permian and Devonian rocks consist of sandstone, conglomerate, siltstone, and argillite, and letter chert and limestone (Wilson and others, 1998). Near the abandoned Dunkle mine, coal deposits of Tertiary age overlie the layered rocks. These rocks include serpentine, gabbro, diorite, quartz diorite, and granite.

The soil characteristics in the Dunkle Mine area are only generally known. Based on work by the National Resource Conservation Service in 1979, the primary soil in the area is classified as *pergelic cryorthods,* a very gravelly, hilly to steep rough mountainous soil association. Typically, the soils have been formed in very gravelly and stony colluvium and glacial drift under a cover of alpine tundra vegetation. Some discontinuous permafrost is present. Vegetation consists of willow-alder shrub communities to bottomland white spruce. Moist tundra covers relatively gentle or level ground above the streams, and dry alpine tundra grows on the steep ground throughout this area.

Climate of the study area is transitional between maritime and continental with the Alaska Range acting as a barrier. The mountains hinder the northward movement of storms from the Gulf of Alaska up the Susitna River Basin. As the air is driven upward over the Alaska Range, the southern flank receives a greater amount of precipitation. The average annual temperature for the area is about -4°C,

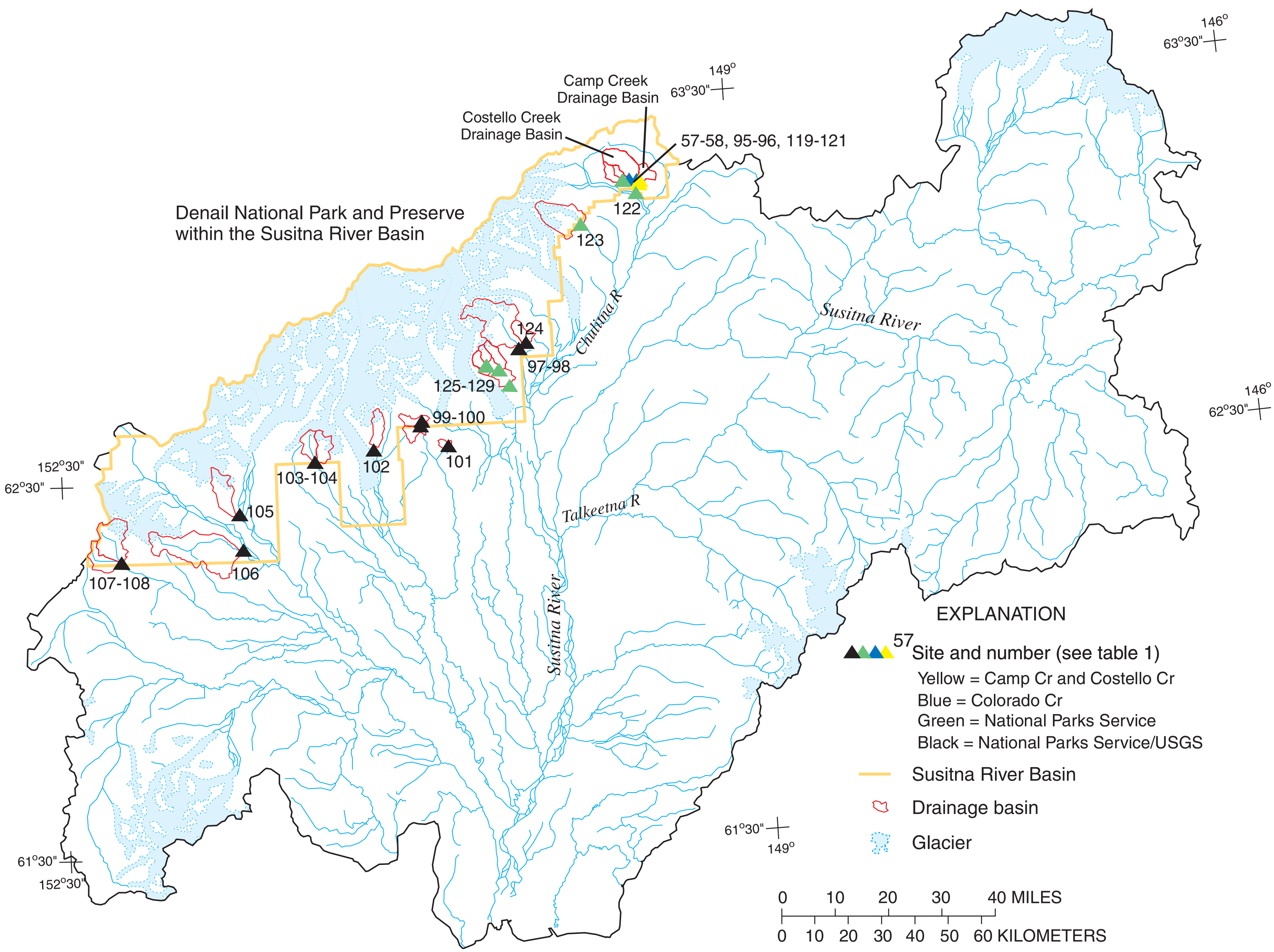

Figure 5. Locations and drainage basins of sampling sites in south side of Denali National Park and Preserve.

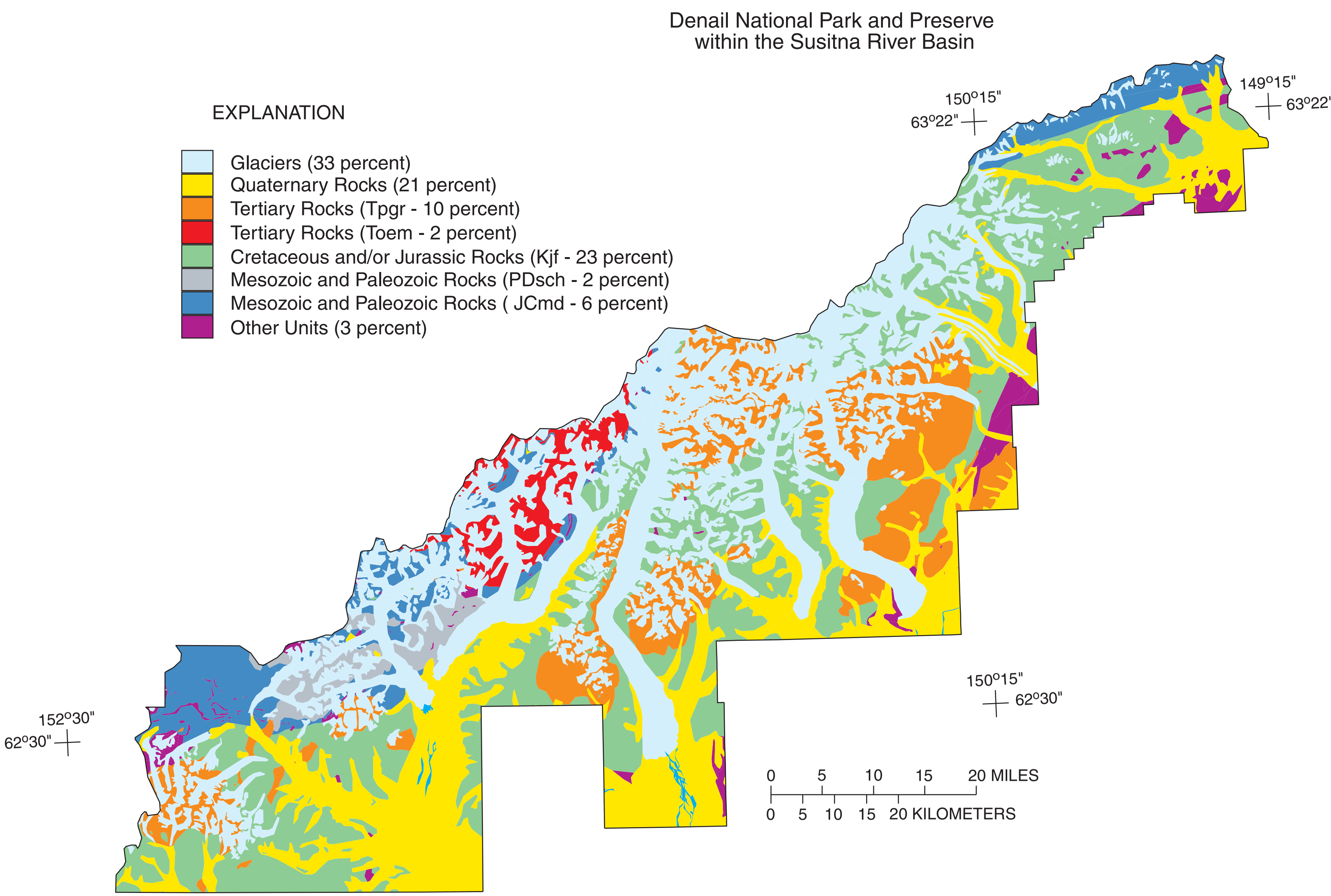

Figure 6. Geology of the south side of Denali National Park and Preserve (from Wilson and others, 1998).

with annual precipitation ranging from 60 to 80 inches, and snowfall averaging 119 inches.

Camp Creek and Costello Creek are located in the north portion of the Susitna River Basin (fig. 2). Camp Creek drains an area of 7.5 mi^2 (fig. 7). No glaciers are present in the basin. Quaternary deposits comprise most of the basin and vegetation is primarily dwarf brush (heaths and willows), wet sedge tussocks, and mosses. Mean basin elevation of Camp Creek is about 3,100 ft and the basin slope is 4 percent. The Dunkle Mine is located near the mouth of Camp Creek (fig. 3) and produced 64,000 tons of lignitic to subbituminous coal from underground-mining operations during 1940-54. Costello Creek, below Camp Creek, drains an area of about 31 mi^2 (fig. 8). Glaciers are present in the headwaters of the basin. Quaternary, Cretaceous, and Jurassic deposits are all present in the basin. Vegetation is similar to Camp Creek. Mean basin elevation is about 4,300 ft and the basin slope is about 7 percent.

The remaining water-quality sites are distributed throughout the south side of DNPP (fig. 5, table 1). One site (101, Long Creek near Takeetna) is located outside the park boundary. Drainage areas of these sites range from 2.6 to 83.4 mi^2. Most of the sites are located in the foothills of the Alaska Range. Greater than one-half the sites have some glaciers present in their basin (fig. 5).

Mining did occur in the Bear Creek Basin, though just a few acres in a side drainage were disturbed. Long Creek also had limited mining in the upper reaches, on the order of a few acres. There were numerous claims in the Colorado Creek Basin. These claims were located in a 2-mile stretch from the mouth of the creek upstream. The Silver King Mine was located in this area.

Methods of Data Collection And Analysis

Water-quality samples were collected on a monthly basis during June through September in 1999 and 2000, when most runoff occurs in the study area. Streambed samples, biological samples, physical habitat surveys, and fish tissue samples were collected at various times during 1999 and 2000.

Water samples collected from Camp Creek and Costello Creak were analyzed for suspended sediment, field param-

Figure 7. Camp Creek (photograph by Tim Brabets, U.S. Geological Survey).

eters, major ions and dissolved solids, nutrients, organic carbon, and trace elements. The field-collection and processing equipment used was made from Teflon, glass, or stainless steel to prevent sample contamination and to minimize analyte losses through adsorption. All sampling equipment was cleaned prior to use with a nonphosphate laboratory detergent and then rinsed with distilled water and finally by stream water just prior to sample collection. Depth integrated water samples were collected across the stream by using the equal-width-increment method (Edwards and Glysson, 1988) and processed in the field using methods and equipment described by Shelton (1994). Samples for organic-carbon analysis were collected separately by dipping a baked glass bottle in the centroid of flow. Samples to be analyzed for dissolved constituents were filtered through 0.45-*u*m capsule filters. Water samples were sent to the USGS National Water-Quality Laboratory in Lakewood, Colorado, for analysis using standard USGS analytical methods (Fishman and Friedman, 1989; Patton and Truitt, 1992; Fishman, 1993). Suspended-sediment samples were sent to the USGS Sediment Analysis Laboratory in Vancouver, Washington, for concentration and particle size analysis.

A Hydrolab or Yellow Springs Instrument (YSI) meter was used to measure water temperature, dissolved-oxygen concentration, specific conductance, and pH at the time of sampling. Discharge measurements were made at the time of sampling using methods outline by Rantz and others (1982).

Edwards and Tranel (1998) outlined data collection and laboratory methods for the NPS study. Collection and analysis of suspended-sediment samples and field parameters by NPS personnel followed USGS methods. Collection of organic carbon and major ion samples were somewhat different, but the preservative and laboratory analytical techniques followed USGS procedures. Thus it was felt the NPS data were comparable to the USGS data.

Streambed sediments were sampled from several depositional areas at each site. Sediments were collected from the surface of the streambed using Teflon tubes or Teflon coated spoons and composited in glass bowls (Shelton and Capel, 1994). Two types of sample were obtained from this

Figure 8. Costello Creek (photograph by Tim Brabets, U.S. Geological Survey).

Table 1. Water-quality sites, south side Denali National Park and Preserve, Alaska

[All values in square miles; Tpgr, Tertiary Paleocene rocks consisting of granite; Kjf, Cretaceous and/or Jurassic sedimentary rocks belonging to the Kahiltna Flysch sequence]

Map number[1] (figure 5)	Latitude/longitude or USGS station number	Station name	Area	Glaciers	Quaternary	Tpgr	Kjf
57	63°16'29"149°35'20"	Colorado Creek near Colorado	10.5	0	0.1	0	8.5
58	63°16'18" 149°32'37"	Costello Creek near Colorado	22.7	0.7	4.0	0	15.9
95	15292302	Camp Creek at mouth near Colorado	7.5	0	5.4	0	1.0
96	15292304	Costello Creek below Camp Creek near Colorado	30.8	0.7	10.0	0	16.9
119	63°16'13" 149°31'42"	Costello Creek above Camp Creek near Colorado	23.3	0.7	4.6	0	15.9
120	63°16'26" 149°37'35"	East Fork Colorado Creek near Colorado	3.3	0	0	0	2.7
121	63°16'20" 149°37'51"	West Fork Colorado Creek near Colorado	6.2	0	0	0	4.9
122	63°14'14" 149°33'15"	Colorado Creek near mouth near Colorado	12.0	0	1.3	0	8.5
123	63°09'42" 149°53'41"	Ohio Creek near Colorado	39.3	14.3	0.6	0	24.2
124	62°51'12" 150°15'48"	Cloud Creek near Talkeetna	2.6	0	0.9	0.8	0
97	62°50'12" 150°18'27"	Crystal Creek at mouth near Talkeetna	7.2	0	1.7	3.7	1.8
98	62°50'14" 150°18'32"	Coffee River above Crystal Creek near Talkeetna	59.2	15.6	4.7	37.1	1.8
125	62°47'43" 150°30'31"	Alder Creek above Whistler Creek near Talkeetna	5.4	0.1	0.1	1.2	4.0
126	62°47'48" 150°30'10"	Whistler Creek near Talkeetna	5.2	1.0	0.1	2.4	1.7
127	62°47'00" 150°26'03"	Alder Creek above Slide Creek near Talkeetna	16.5	1.1	1.2	7.3	6.9
128	62°47'00" 150°25'41"	Slide Creek near Talkeetna	9.3	1.1	0	5.9	2.3
129	62°40'31" 150°20'05"	Alder Creek near mouth near Talkeetna	35.8	2.2	5.3	19.6	8.7
99	62°38'34" 150°54'33"	Bear Creek near Talkeetna	9.7	0	3.2	0	6.4
100	62°39'20" 150°54'03"	Wildhorse Creek near Talkeetna	7.3	0	2.6	0	4.7
101	62°35'10" 150°45'04"	Long Creek near Talkeetna	3.8	0	1.7	0	1.2
102	62°35'01" 151°11'29"	Hidden Creek near Talkeetna	12.8	2.6	2.1	4.3	3.8
103	62°33'24" 151°32'16"	Snowslide Creek at mouth near Talkeetna	14.2	4.7	0.1	8.7	0.7
104	62°33'25" 151°32'18"	Cripple Creek above Snowslide Creek near Talkeetna	12.9	1.2	0.1	8.2	3.4
105	62°25'22" 151°59'22"	Cascade Creek at mouth near Talkeetna	23.7	5.0	5.9	1.2	11.6
106	62°19'36" 151°58'27"	Fourth of July Creek at mouth near Talkeetna	83.4	2.7	34.6	0.8	44.3
107	62°17'59" 152°41'05"	Morris Creek at mouth near Talkeetna	16.6	0.5	6.9	0.2	9.0
108	62°18'00" 152°41'06"	Kichatna River above Morris Creek near Talkeetna	35.2	7.5	4.8	8.4	14.5

[1]The Cook Inlet Basin NAWQA study unit established a uniform numbering system for all surface water sites located in the study basin. For a complete list of stations and numbers see http://alaska.usgs.gov/projects/Nawqa/water.sites.htm

composite: samples for semi-volatile organic compounds (SVOCs) and particle size analysis were passed through a 2-mm stainless-steel sieve; and a sample for trace elements was passed through a 0.063-mm Nylon sieve. Up to 250 mL of stream water was used for sieving the trace-element sample. Samples for SVOCs and trace elements were chilled after sieving. Water included in the trace-elements was decanted after very fine-grained sediments had settled.

Details of laboratory methods related to the analysis of SVOCs in streambed sediments are described by Furlong and others (1996). The analytical results for constituents are expressed as concentrations when they exceed a minimum reporting limit (MRL), or estimated (E) when they are detected, but they are less than the MRL. Arbogast (1990) describes laboratory procedures followed for processing streambed samples for trace element analysis. Trace elements in streambed sediments were analyzed following a total digestion procedure. As such, these data may be more useful for differentiating source areas of sediments than for detecting anthropogenic effects, or for determining bioaccumulation in fish.

Slimy sculpin, *Cottus cognatus*, was chosen as the most appropriate species for tissue analysis. This species is non-migratory and a bottom-feeding omnivore, which are characteristics necessary for interpretation of results (Crawford and Luoma, 1993). Crawford and Luoma (1993) recommend analysis of whole fish livers for trace-elements. Because adult slimy sculpin are small, whole fish were used for analysis of trace elements.

Fish were collected using a backpack electrofishing unit and a seine. The seine would be set across a riffle and the electrofishing would begin about 20 ft upstream and work down toward the seine. Slimy sculpin captured on the seine were placed in a bucket of stream water until sufficient numbers had been collected to constitute a sample (30 grams). Each fish in the composite sample was weighed and measured. Fish used for trace element samples were double bagged in plastic. Composited samples were immediately placed on wet ice and then to a portable freezer. Whole sculpin were analyzed for trace elements at the NWQL using methods described by Hoffman (1996).

Collection of stream characteristics was completed at 11 equally spaced transects along an established reach. The data on physical characteristics of each stream reach were collected according to protocols described by Fitzpatrick and others (1998). Physical characterization of each stream reach included measurements of riparian and instream aquatic-habitat features. Habitat features measured included flow, aspect, open-canopy angles, and canopy closure, as well as the presence of any submerged habitat features such a boulders or woody debris. Physical characteristics of each stream reach were documented with a set of notes and photographs taken during site visits. These observations included a detailed hand sketch of each study reach depicting major geomorphic features such as sloughs, riffles, and rapids within the identified study reach.

Biological samples were collected according to protocols outlined by Cuffney and others (1993), Meador and others (1993), and Porter and others (1993). An assessment of the algal community was done to identify algal density, as well as the species of algae present at stream reaches. Two types of samples were collected: (1) a quantitative sample was collected from known surface areas and composited to determine density and species composition, and (2) the variety of algal habitats within a reach were qualitatively sampled for a more complete assessment of the species composition for the stream reach.

Benthic macroinvertebrates were sampled using two methods that correspond to those used for algae samples (Cuffney and others, 1993). One sample, collected from the Richest Targeted Habitat (RTH), was used to quantify the relative density of macroinvertebrates. A second sample, the Qualitative Multi-Habitat (QMH), was used to determine macroinvertebrate taxa present at the sites by sampling all the available habitats. An RTH sample is the composite of five 0.25 m^2 areas in which the streambed is disturbed to wash macroinvertebrates into a collection net. At all sites, riffles were sampled as the richest habitat. The QMH sample is collected from the variety of habitats present in the stream reach and uses a dip net and hand picking of macroinvertebrates from woody debris. The two sample methods differ in the mesh size of the collection nets: RTH samples are collected with a 425-*u*m mesh, and QMH samples are collected with a 210-*u*m mesh.

Macroinvertebrates were identified at the USGS National Water-Quality Laboratory's Biological Unit. Subsampling techniques are used in the identification and enumeration of macroinvertebrates at the Biological Unit. RTH samples are subsampled with a technique that is based on a 300-organism subsample. If fewer than 300 organisms are present in a sample, subsampling is not necessary. QMH samples are subsampled by timed method rather than by specific number of organisms. Because the abundance of organisms is not determined for QMH samples, the taxonomist need only sort out a few individuals of each taxon for identification.

Raw data from benthic macroinvertebrate samples are presented in appendix 1. Before analyzing data for the number of taxa present and calculating descriptive metrics, ambiguities were resolved by distributing the abundances of taxonmic 'parents' to the respective taxonomic 'children' based on the relative abundances of the children. For example, the abundance of individuals only identified to the family level were distributed among the genera identified for that family, if any, and the abundance of individuals only identified to genera were distributed among the species identified for that genera, if any. This process provides a more accurate estimate of richness while preserving the overall sample abundance.

After the data were collected, checked, and compiled, data analysis was undertaken. The concentrations of various water-quality constituents from Camp Creek, Costello Creek, and the other streams were evaluated in relation to established water-quality criteria. For example, trace-element concentrations in streambed sediments were compared with those of previous NAWQA studies and guidelines established by the Canadian Council of Ministers of the Environment. If concentrations of particular water-quality constituents did not exceed these criteria it was assumed that the Dunkle Mine has not affected the water quality of Camp Creek or Costello Creek. Basin characteristics of each watershed such as drainage area, geology type, or percent glaciers were also used in statistical analysis of the data.

WATER QUALITY OF CAMP CREEK, COSTELLO CREEK, AND OTHER SELECTED STREAMS

Water-quality data collected at Camp Creek and Costello Creek included field parameters (streamflow, specific conductance, pH, water temperature, dissolved oxygen), suspended sediment, major inorganic ions, and nutrients. More specific data included water samples analyzed for dissolved organic carbon (DOC) and trace elements, bed sediments analyzed for trace elements and semi-volatile organic compounds, and fish tissue analyzed for trace elements. Biological data included samples of invertebrates and algae. Site visits were made to Camp Creek and Costello Creek throughout the summer months during June through September 1999 and 2000.

The NPS collected water-quality data at a number of sites in DNPP from 1994 to 1996 (Edwards and Tranel, 1998). In addition to Costello Creek and Camp Creek, 27 other sites located on the south side of DNPP were sampled (figs. 2 and 5, table 1). The water-quality data consisted of physical properties (streamflow, specific conductance, pH, water temperature, and dissolved oxygen), major ions, dissolved organic carbon (DOC), and suspended sediment. These water-quality data were compared with the water-quality data collected from Camp Creek and Costello Creek to determine similarities or differences, and to better understand the water quality of this portion of the Cook Inlet Basin. No trace element or semi-volatile organic data were collected by the National Park Service.

Physical Properties

Streamflow and Suspended Sediment

Streamflow at Camp Creek and Costello Creek ranged from 4.1 to 72 ft^3/s and from 45 to 258 ft^3/s, respectively (tables 2-3). The highest streamflows measured at Camp Creek (49 ft^3/s and 72 ft^3/s) were during June 1999 and 2000, at the time of maximum or near maximum snowmelt. Relatively high streamflows also occurred at this time at Costello Creek, but the highest discharge measured occurred in July 2000 (258 ft^3/s). Although only one streamflow measurement was made in July, most likely this time period represents the time of glacier melt contribution. Based on a per unit runoff basis, streamflow from Costello Creek is higher than Camp Creek except for the June period. Concentrations of suspended sediment were usually higher at Costello Creek, the glacial basin, than at Camp Creek. Concentrations varied with streamflow.

Similar to Camp Creek and Costello Creek, streamflow at the other selected sites in the south side of DNPP from previous studies was dependent on time of year, drainage area, and basin characteristics (table 4). The largest streams, the Kichatna River and Fourth of July Creek, were often unwadable and no discharge measurements were made at these sites. Comparing the discharges on a per unit basis indicates the wide variation in streamflow at many of the sites, reflecting the time of year or hydrologic condition. For example, the lowest unit discharge was 0.5 $ft^3/s/mi^2$ measured at Camp Creek and the highest unit discharge was 25 $ft^3/s/mi^2$ measured at Cripple Creek (table 4). There was also a wide variation in suspended sediment concentrations at these sites. Most of the variation is due to the amount of flow and whether or not glaciers are present in the basin. For example, the highest measured suspended sediment concentrations, 5,230 mg/L and 4,900 mg/L, were measured at two glacial basins, Ohio Creek and Whistler Creek. Concentrations of suspended sediment from streams without glaciers present in their watersheds usually were less than 100 mg/L.

Specific Conductance

Specific conductance is determined by the type and concentration of ions in solution. It is a readily measured property that can be used to indicate the dissolved-solids or ion content in water. Values of specific conductance ranged from 12 to 67 *u*s/cm at Camp Creek and from 74 to 224 *u*s/cm at Costello Creek (tables 2 and 3). Specific conductance was consistently higher at Costello Creek, reflecting greater dissolved mineral content. At both sites, greater values of specific conductance were measured at the lowest streamflow, reflecting more contribution from ground water. At the other sites sampled by the NPS, specific con-

Table 2. Discharge, physical properties, and suspended sediment measured at Camp Creek at mouth near Colorado, Alaska (station 15292302)

[ft^3/s. cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; µs, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ^oC, degrees Celsius; -- not sampled; <, less than]

Date (mm/dd/yy)	Discharge (ft^3/s)	Unit discharge ($ft^3/s/mi^2$)	Specific conductance (µs/cm)	pH (standard units)	Water temperature (^oC)	Dissolved oxygen (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Suspended sediment (mg/L)
07/14/95	17.4	2.3	67	7.1	10	11.3	28	<1
09/11/95	22.3	3.0	42	6.8	7.4	11.8	19	10
06/02/96	21.6	2.9	34	7.5	9.3	11.5	14	143
09/06/96	4.1	0.5	61	7.5	4.5	12.7	24	22
06/04/99	72	9.6	12	7.3	2.5	12	10	58
08/03/99	8.0	1.1	51	7.4	10	9.8	22	2
09/20/99	5.1	0.7	60	7.4	4.5	12	31	2
06/01/00	49	6.5	37	7.0	0.1	14	15	39
07/11/00	19	2.5	53	7.4	--	--	16	23
08/08/00	9.3	1.2	58	7.3	14	10	24	5
09/07/00	5.2	0.7	59	7.5	5.3	13	25	<1

Table 3. Discharge, physical properties, and suspended sediment measured at Costello Creek below Camp Creek near Colorado, Alaska (station 15292304)

[ft^3/s. cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; µs, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ^oC, degrees Celsius; -- not sampled]

Date (mm/dd/yy)	Discharge (ft^3/s)	Unit discharge ($ft^3/s/mi^2$)	Specific conductance (µs/cm)	pH (standard units)	Water temperature (^oC)	Dissolved oxygen (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Suspended sediment (mg/L)
07/14/95	144	4.7	171	7.5	6.6	11.4	49	43
09/11/95	105	3.4	224	7.8	5.9	12.3	62	67
06/02/96	112	3.6	152	7.8	8.4	12.0	43	109
09/06/96	45	1.5	260	8.1	3.7	13.5	69	9
06/04/99	179	5.8	74	7.8	4.0	12.1	42	48
08/03/99	104	3.4	173	8.1	10	10.2	53	178
09/20/99	51	1.6	224	8.1	5.4	11.7	63	7
06/01/00	134	4.4	89	7.3	1.3	14.4	31	63
07/11/00	258	8.4	133	7.9	--	--	44	220
08/08/00	103	3.3	178	8.1	11	10.3	57	20
09/07/00	45	1.5	218	8.0	6.1	12.3	64	1

Table 4. Ranges in streamflow and physical properties for water-quality sites on the south side of Denali National Park and Preserve, Alaska (from Edwards and Tranel, 1998)

[ft^3/s. cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; µs, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ^oC, degrees Celsius; -- not sampled]

Site number (figure 5)	Station Name	Discharge (ft^3/s)	Unit discharge ($ft^3/s/mi^2$)	Specific conductance (µs/cm)	pH (standard units)	Water temperature (^oC)	Dissolved oxygen (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Suspended sediment (mg/L)
95	Camp Creek at mouth near Colorado	4.1-22.3	0.5-3.0	33-71	6.7-7.5	4.5-10.4	11.3-12.7	14-28	0-143
119	Costello Creek above Camp Creek near Colorado	45-144	2.0-6.3	144-241	7.5-8.1	5.9-8.4	11.4-13.5	43-62	9-109
120	East Fork Colorado Creek near Colorado	4.8-23.5	1.4-7.1	178-551	7.8-8.1	4.6-7.2	11.9-13.2	36-114	8-165
121	West Fork Colorado Creek near Colorado	7.7-59.0	1.2-9.5	565-580	7.7-8.0	4.1-6.3	11.5-13.3	25-85	3-67
122	Colorado Creek near mouth near Colorado	19.3-54.6	1.6-4.6	170-443	7.7-8.1	4.1-8.4	11.4-13.2	32-95	6-100
123	Ohio Creek near Colorado	--	--	86-147	7.3-7.8	1.3-1.9	13.5-15.3	36-39	389-5,230
124	Cloud Creek near Talkeetna	9.2-41.5	3.5-16.0	37-51	7.2-7.6	4.0-10.3	10.6-13.1	10-17	0-2
97	Crystal Creek at mouth near Talkeetna	27.6-112	3.8-15.6	23-30	6.5-7.1	5.4-9.5	10.8-13	6-9	0-7
125	Alder Creek above Whistler Creek near Talkeetna	21.2-39.8	3.9-7.4	81-112	7.1-7.6	3.6-8.4	11.6-13.1	10-18	0-4.4
126	Whistler Creek near Talkeetna	26.2-51.9	5.0-10.0	19-77	7.0-7.8	3.3-8.7	11.5-13.1	20-22	2.0-4,900
127	Alder Creek above Slide Creek near Talkeetna	71.8-78.7	4.3-4.8	66-77	7.3-7.7	5.0-6.9	12.1-13.6	19-20	1-147
128	Slide Creek near Talkeetna	36.6-61.9	3.9-6.6	34-38	7.1-7.5	5.8-8.6	12.2-12.6	9-10	6.5-8.8
129	Alder Creek near mouth near Talkeetna	170-470	4.7-13.1	37-58	6.3-7.5	6.1-11.1	11.4-12.2	10-18	0-447
99	Bear Creek near Talkeetna	13.4-107	1.4-11.0	32-66	6.6-7.6	4.2-8.4	10.8-12.6	16-30	0-15
100	Wildhorse Creek near Talkeetna	13.6-84.9	1.9-11.6	36-87	7.2-7.8	4.7-9.3	11.0-12.4	14-34	0-2
101	Long Creek near Talkeetna	4.0-14.5	1.0-3.8	32-56	6.8-7.4	8.0-11.9	11.4-11.8	12-20	0-1
102	Hidden Creek near Talkeetna	50-184	3.9-14.3	20-40	6.7-7.4	6.1-9.2	11.5-12.9	8-15	4-108
103	Snowslide Creek at mouth near Talkeetna	120-300	8.4-21.1	8-11	6.3-7.8	3.4-7.5	12.1-13.3	2-25	60-137
104	Cripple Creek above Snowslide Creek near Talkeetna	51-323	4.0-25.0	10-20	6.5-7.4	3.2-10.0	10.9-13.2	3-7	4-88
105	Cascade Creek at mouth near Talkeetna	209-330	8.8-13.9	27-43	7.0-8.5	4.7-9.6	11.7-12.4	10-16	7-92
106	Fourth of July Creek at mouth near Talkeetna	414	5.0	72-121	7.3-7.6	6.7-11.4	11.5-11.7	19-23	10-291
107	Morris Creek at mouth near Talkeetna	63.3-180	3.8-10.8	172-297	7.5-8.0	3.6-6.3	12.4-13.5	12-20	4-10
108	Kichatna River above Morris Creek near Talkeetna	-	--	51-221	7.3-7.8	2.8-6.2	12.0-13.7	9-30	23-154

ductance values were similar to Camp Creek and Costello Creek with the exception of sites in the Colorado Creek watershed (sites 120-122). Specific conductance values at these sites ranged between 170 and 580 *u*s/cm, indicating a greater dissolved mineral content in this stream.

pH

The pH of water is a measure of its hydrogen-ion activity and can range from 0 (very acidic) to 14 (very alkaline) standard units. The pH of river water not affected by contamination is typically between 6.5 and 8.0 standard units (Hem, 1985). For fish growth and survival, the pH should remain between 6.5–9.0 standard units. Values of pH for both Camp Creek and Costello Creek were within this range. Most samples from the other streams on the south side of DNPP had pH values within this range although some samples from Alder Creek (site 129) and Snowslide Creek (site 103) did have pH values of 6.3.

Water Temperature

Water temperature is important in both physiochemical and biological processes such as oxygen solubility and fish metabolism and growth rates. Ranges in water temperature at Camp Creek and Costello Creek were highly seasonal. At Camp Creek, water temperatures were the coldest in June (2.5 ^{o}C and 0.1 ^{o}C), reflecting the snowmelt runoff, and highest during August (10 ^{o}C and 14 ^{o}C) (table 2). Temperatures cooled during the fall season. This pattern was essentially the same at Costello Creek (table 3), though temperatures in August were lower than Camp Creek (10.0 ^{o}C and 10.9 ^{o}C), reflecting the cooling effect from glacier and snow melt. Similarly, at the NPS sites, water temperatures varied with season. Lowest water temperatures occurred in the spring or early summer period at the time of snowmelt and highest water temperatures occur mid to late summer. The lowest water temperature measured at these sites was 1.3 ^{o}C at Ohio Creek and the highest water temperature measured was 11.4 ^{o}C measured at Fourth of July Creek (table 4).

Dissolved Oxygen

The dissolved-oxygen concentration in a stream is controlled by several factors, including water temperature, air temperature and pressure, hydraulic characteristics of the stream, photosynthetic or respiratory activity of stream biota, and the quantity of organic matter present. Salmon and other fish require well-oxygenated water at every stage in their life and young fish are more susceptible to oxygen deficiencies than adult fish. Dissolved oxygen concentrations at Camp Creek and Costello Creek ranged from 9.8 to 14.2 mg/L and from 10.2 to 14.4 mg/L respectively. All concentrations were sufficient to support fish. At the other sites, measured dissolved oxygen concentrations ranged from 10.6 mg/L to 15.3 mg/L indicating that during the summer period these streams are well oxygenated.

Alkalinity

Alkalinity is a measure of the capacity of the substances dissolved in water to neutralize acid. In most natural waters, alkalinity is produced mainly by bicarbonate and carbonate (Hem, 1985), which are ions formed when carbon dioxide or carbonate rocks dissolve in water. Alkalinity concentrations (reported as equivalent concentrations of calcium carbonate ($CaCO_3$)) for Camp Creek ranged from 10 to 31 mg/L (table 2) and for Costello Creek ranged from 31 to 64 mg/L as $CaCo_3$ (table 3). These alkalinity concentrations indicate that water in Camp Creek and Costello Creek has a low buffering capacity and limited availability of inorganic carbon (Hem, 1985). Also, given the range of pH values of Camp Creek and Costello Creek, all of the alkalinity can be assigned to dissolved bicarbonate (Hem, 1985). Most alkalinity concentrations measured at the other sites on the south side of DNPP indicated a lower buffer capacity than Costello and Camp Creeks (table 4). For example, at Crystal Creek and Cripple Creek, alkalinity concentrations were less than 10 mg/L (as $CaCO_3$) for all samples. However, at sites located in the Colorado Creek Basin, measured alkalinity concentrations were the highest of all sites in the south side of DNPP. Concentrations at these sites ranged from 25 mg/L to 114 mg/L as $CaCO_3$. Similar to Camp and Costello Creeks, all the alkalinity measured at these sites can be assigned to dissolved bicarbonate.

Major Ions and Dissolved Solids

Water samples collected from Camp Creek and Costello Creek for this study were analyzed for major ions and dissolved solids (tables 5-6). Major ions and dissolved solids in rivers consist of inorganic minerals and are derived primarily from soil and rock weathering. Concentrations generally are greatest in streams draining basins with rocks and soils that contain easily dissolved minerals. The dissolved solids concentrations, 16 to 46 mg/L at Camp Creek (table 5) and 62 to 134 mg/L at Costello Creek (table 6), reflect the fact that these types of rocks and soil are not present in the Camp Creek and Costello Creek watersheds. At the other sites sampled in the south side of DNPP, similar concentrations of dissolved solids were measured with the exception of the sites in the Colorado Creek watershed (sites 120-122) (table 7). At these sites, dissolved solids concentrations ranged from 75 to 289 mg/L, which may indicate differences in rocks and soils.

Calcium is usually the dominant positively charged ion in most natural waters, followed by magnesium (Hem, 1985). Concentrations of calcium and magnesium at Camp

Table 5. Major dissolved inorganic constituents measured in water samples collected from Camp Creek at mouth near Colorado, Alaska (station 15292302)

[all values in mg/L; E, estimated; <, less than, * collected by the National Park Service]

Date (mm/dd/yy)	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride	Silica	Dissolved solids
07/14/95*	8.2	2.3	2.2	0.3	36	4.2	0.1	--	35
09/11/95*	4.3	1.7	1.8	0.2	25	2.8	0.4	--	23
06/02/96*	4.1	1.1	1.2	0.3	18	1.6	0.1	--	16
09/06/96*	5.4	2.0	2.2	0.2	31	4.3	0.1	--	27
06/04/99	2.4	0.8	0.6	0.3	12	0.4	0.2	2.5	37
08/03/99	6.3	1.8	1.9	0.4	27	2.6	<.1	5.7	45
09/20/99	6.6	1.9	2.1	0.2	38	3.0	<0.3	6.0	42
06/01/00	4.1	1.3	1.1	0.5	18	0.9	E0.2	4.0	28
07/11/00	4.7	1.4	1.3	E0.2	21	2.0	<0.3	4.6	33
08/08/00	6.5	1.9	1.8	E0.2	31	2.0	<0.3	4.6	46
09/07/00	6.6	1.8	2.0	0.3	32	2.4	E0.2	5.5	45

Table 6. Major dissolved inorganic constituents measured in water samples collected from Costello Creek below Camp Creek near Colorado, Alaska (station 15292304)

[all values in mg/L; E, estimated, *, collected by National Park Service]

Date (mm/dd/yy)	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride	Silica	Dissolved solids
07/14/95*	19	7.5	2.8	0.5	64	29	0.3	--	87
09/11/95*	16	12	3.6	0.9	81	47	0.4	--	120
06/02/96*	15	7.7	2.9	0.7	56	28	0.4	--	71
09/06/96*	26	12	4.9	0.7	90	58	1.3	--	93
06/04/99	12	6.9	2.6	0.8	51	20	0.8	3.1	93
08/03/99	19	7.8	3.6	0.6	65	28	<0.1	3.5	106
09/20/99	23	11	4.3	0.6	77	44	0.6	4.3	134
06/01/00	10	6.2	2.7	0.8	36	9.9	0.4	4.3	62
07/11/00	13	6.1	2.5	0.5	57	22	E0.3	3.2	82
08/08/00	19	8.6	3.9	0.6	74	30	0.3	3.6	111
09/07/00	21	10	4.1	0.7	83	39	0.6	3.8	128

Table 7. Ranges in concentrations of water-quality samples collected at sites located in the south side Denali National Park and Preserve, Alaska

[all concentrations in milligrams per liter]

Site number (figure 5)	Station name	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride	Dissolved solids	Dissolved organic carbon
95	Camp Creek at mouth near Colorado	4.1-8.2	1.1-2.3	1.2-2.2	0.2-0.3	1.6-4.3	0-0.4	16-35	4.4-5.7
119	Costello Creek above Camp Creek near Colorado	16-26	7.5-12	2.8-4.9	0.5-0.9	28-58	0.3-1.3	71-120	2.8-5.1
120	East Fork Colorado Creek near Colorado	14-42	12-40	2.6-11	0.6-1.4	48-187	0-0.3	89-275	1.8-6.3
121	West Fork Colorado Creek near Colorado	12-45	9.9-41	3.1-13	0.6-1.2	54-221	0-0.2	75-289	1.2-8.0
122	Colorado Creek near mouth near Colorado	14-42	10-38	3.0-12	0.6-1.4	51-199	0.2-0.25	86-221	1.8-8.0
123	Ohio Creek near Colorado	13-19	4.6-5.5	1.3-1.6	0.3-1.0	23-39	0.0-0.1	42-73	1.6-8.3
124	Cloud Creek near Talkeetna	4.4-7.6	0.3-0.5	0.6-1.0	0.3-0.6	3.1-7.1	0-0.2	13-28	1.1-3.9
97	Crystal Creek at mouth near Talkeetna	1.1-2.4	0.6-2.0	0.5-0.8	0.5-1.0	2.6-3.8	0.0-0.2	11-15	0.8-1.9
125	Alder Creek above Whistler Creek near Talkeetna	4.3-7.6	0.4-0.9	0.6-1.0	0.7-1.0	4.4-16	0-0.2	18-29	0.8-2.5
126	Whistler Creek near Talkeetna	9.5-11	0.7-0.8	0.7-0.9	0.8-1.2	9.3-12	0-0.1	9.3-34	1.0-1.9
127	Alder Creek above Slide Creek near Talkeetna	9.6-12	0.8-0.9	0.8-1.0	0.7-1.0	12-13	0-0.2	33-38	1.3-5.5
128	Slide Creek near Talkeetna	4.0-5.3	0.5-0.7	0.7-0.9	0.6-0.8	4.6-7.4	0-0.2	13-18	0.7-2.7
129	Alder Creek near mouth near Talkeetna	4.3-7.6	0.4-0.9	0.6-1.0	0.7-1.0	4.4-16	0-0.2	18-29	0.5-2.0
99	Bear Creek near Talkeetna	4.1-9.3	1.0-2.2	0.7-1.1	0.1-0.3	2.0-4.9	0-0.2	16-33	1.1-5.9
100	Wildhorse Creek near Talkeetna	4.3-11	1.0-3.5	0.6-1.2	0.1-0.2	1.8-6.0	0-0.2	18-44	1.0-7.0
101	Long Creek near Talkeetna	4.2-4.7	0.6-1.3	1.2-1.9	0.1	2.8-3.9	0.2-0.6	16-28	1.8-2.5
102	Hidden Creek near Talkeetna	1.5-4.7	0.4-0.8	0.6-1.1	0.3-0.5	1.2-2.0	0-0.3	20-40	0.7-1.6
103	Snowslide Creek at mouth near Talkeetna	0.7-7.8	0.1-1.0	0.3-0.8	0.3-1.7	1.0-8.2	0-0.2	4-5	0.6-0.9
104	Cripple Creek above Snowslide Creek near Talkeetna	1.3-2.4	0.2-0.3	0.4-0.6	0.2-0.3	0.8-4.1	0-0.1	5-10	0.6-1.0
105	Cascade Creek at mouth near Talkeetna	2.5-4.9	0.8-1.1	0.5-0.8	0.3-0.5	2.4-3.3	0-0.2	13-19	0.8-1.5
106	Fourth of July Creek at mouth near Talkeetna	9-14	3.1-5.0	0.8-1.0	0.3-0.6	18-35	0.2	36-60	1.0-2.0
107	Morris Creek at mouth near Talkeetna	4.2-4.7	0.6-1.3	1.2-1.9	0.1	2.8-3.9	0.2-0.6	86-148	0.9-3.4
108	Kichatna River	6-26	1.7-9.2	0.5-1.3	0.4-0.6	12-47	0-0.2	57-109	0.6-1.5

Creek ranged from 2.4 to 8.2 mg/L for calcium and from 0.8 to 2.3 mg/L for magnesium (table 5). Concentrations of calcium and magnesium at Costello Creek ranged from 10 to 26 mg/L for calcium and from 6.1 to 12 mg/L for magnesium (table 6). Similar ranges in concentrations were found at the other sites sampled on the south side with the exception of the Colorado Creek sites and Fourth of July Creek. Concentrations of calcium and magnesium ranged as high as 45 mg/L and 41 mg/L respectively at West Fork Colorado Creek (table 7).

Sodium is present in all natural waters, but usually in low concentrations in rivers. Concentrations of sodium at Camp Creek ranged from 0.6 to 2.2 mg/L (table 5) and at Costello Creek from 2.5 to 4.9 mg/L (table 6). Potassium seldom occurs in high concentrations in natural waters (Hem, 1985) and concentrations of this element for both Camp Creek and Costello Creek were less than 1.0 mg/L (tables 5-6). Similar concentrations of these two elements were found at the other sites with the exception of relatively high concentrations of sodium at the Colorado Creek sites. Bicarbonate, which originates from dissolution of sedimentary rocks, was the dominant anion and ranged from 12 to 38 mg/L at Camp Creek (table 5) and from 36 to 83 mg/L at Costello Creek (table 6).

Sulfate in rivers is mostly from the weathering of sedimentary and igneous rocks and biochemical processes. Concentrations of this constituent were noticeably different between Camp Creek and Costello Creek. In Camp Creek, concentrations of sulfate ranged from 0.4 mg/L to 4.2 mg/L (table 5), but at Costello Creek concentrations ranged from 9.9 to 58 mg/L (table 6). The highest concentrations of this element, 221 mg/L, were found from the previous studies at the West Fork Colorado Creek.

Chloride is present in Camp Creek and Costello Creek, but only in small amounts. Concentrations at Camp Creek were less than or equal to 0.4 mg/L (table 5), and concentrations at Costello Creek were less than or equal to 0.8 mg/L (table 6). Similar concentrations of chloride were found at the other sites.

Silica is dissolved from rocks and soils, and concentrations most commonly determined in natural water are between 1 and 30 mg/L as SiO_2 (Hem, 1985). Concentrations of this element ranged from 2.5 mg/L to 6.0 mg/L at Camp Creek (table 5) and from 3.1 to 4.3 mg/L at Costello Creek (table 6).

Concentrations of the major ions for both Camp Creek and Costello Creek were converted to milliequivalents per liter (Drever, 1997). The proportions of the major cations (calcium, magnesium, sodium, and potassium) were plotted on one triangle of the trilinear diagram (fig. 9), the major anions (bicarbonate, chloride, sulfate) were plotted on another triangle of the diagram, and the information from these two triangles was plotted on a third triangle. The trilinear diagram helps display water-chemistry data and determine the composition of the water. Based on the samples collected for this study, the water of Camp Creek would be classified as calcium magnesium bicarbonate and the water of Costello Creek would be classified as calcium bicarbonate sulfate**.**

The concentrations of the other major ions from the other sites sampled on the south side of DNPP were also converted to milliequivalents per liter and the piper diagram was used to indicate the type of water of each stream (fig. 10). Most of the streams located on the south side of DNPP would be classified as calcium bicarbonate, with the exception of streams in the Colorado Creek Basin (fig. 8), which would be classified as magnesium sulfate and Fourth of July Creek (fig. 9), which would be classified as calcium sulfate.

Most of the major ions measured at Camp Creek, Costello Creek, and in the other streams on the south side of DNPP indicated a good statistical relation to specific conductance (table 8). The coefficients of determination (R^2) were 0.61 or greater and the regression equations were statistically valid at a significance level of greater than 99 percent. Thus, valid estimates of concentrations of these constituents can be calculated from the equations given measured values for specific conductance.

Nutrients and Organic Carbon

Nitrogen is an important water-quality constituent, in part because it is an important component of the protoplasm of aquatic biota. For this study water samples were analyzed for several forms of nitrogen. Nitrate and nitrite represent most of the dissolved nitrogen in well-aerated streams. Total ammonia plus organic nitrogen most represent the nitrogen compounds in solution and associated with colloidal material.

All concentrations of the various nitrogen forms were less than 1.0 mg/L (tables 9 and 10). Due to its toxicity to freshwater aquatic life, the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 1976) suggests a limitation of 0.02 mg/L of ammonia (as un-ionized ammonia, NH_3) for waters to be suitable for fish propagation. Based on the values of ammonia, pH, and water temperature in Camp Creek and Costello Creek (tables 9 and 10) the un-ionized ammonia, was calculated as 0.59 percent of dissolved ammonia (interpolated from table 3, U.S. Environmental Protection Agency, 1976, p. 11). Even at the maximum concentration of dissolved ammonia (0.014 mg/L for Camp Creek, 0.007 mg/L for Costello Creek), the concentration of un-ionized ammonia is well below the USEPA recommended criteria for fish propagation.

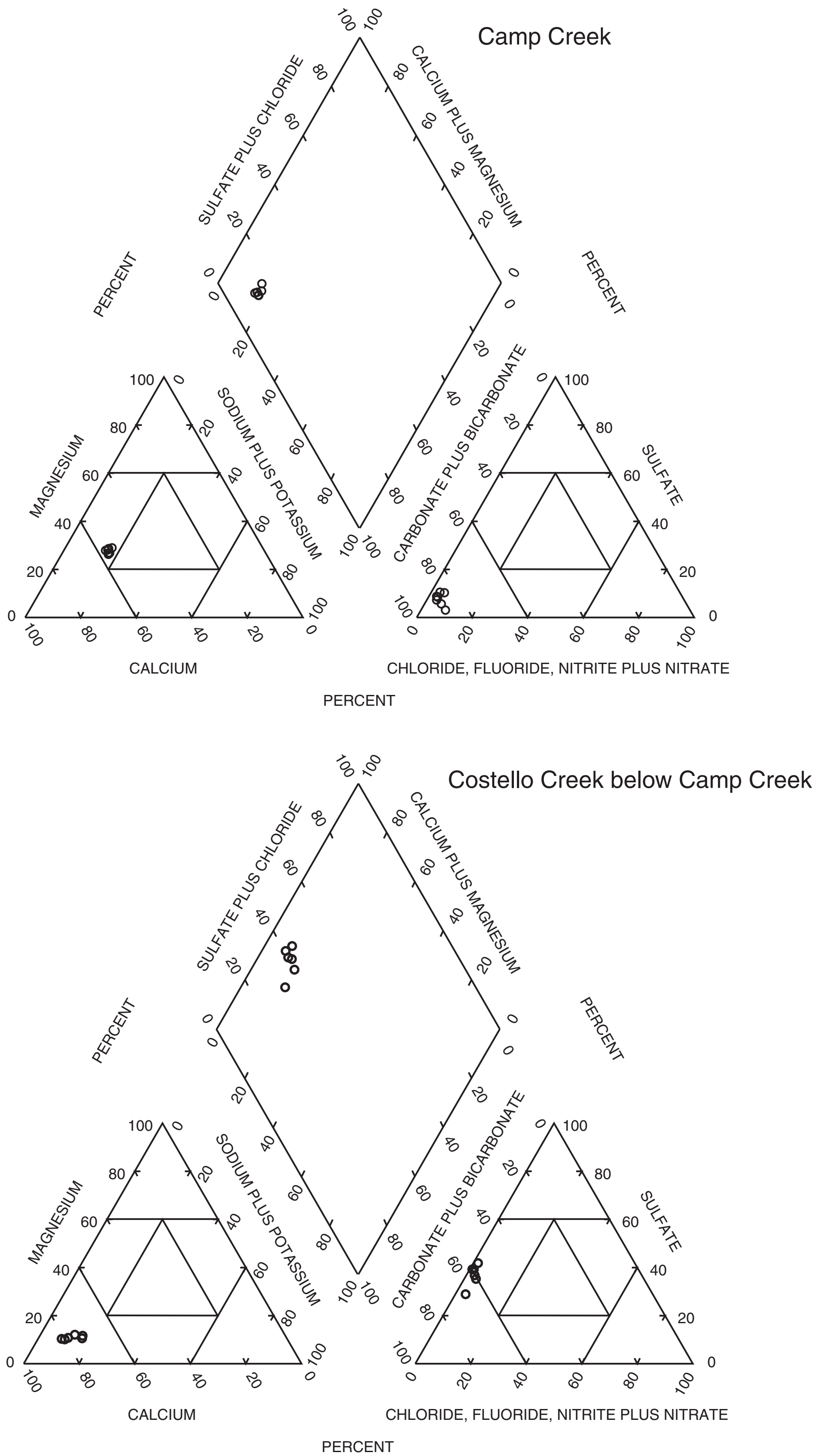

Figure 9. Trilinear diagram of water samples from Camp Creek and Costello Creek.

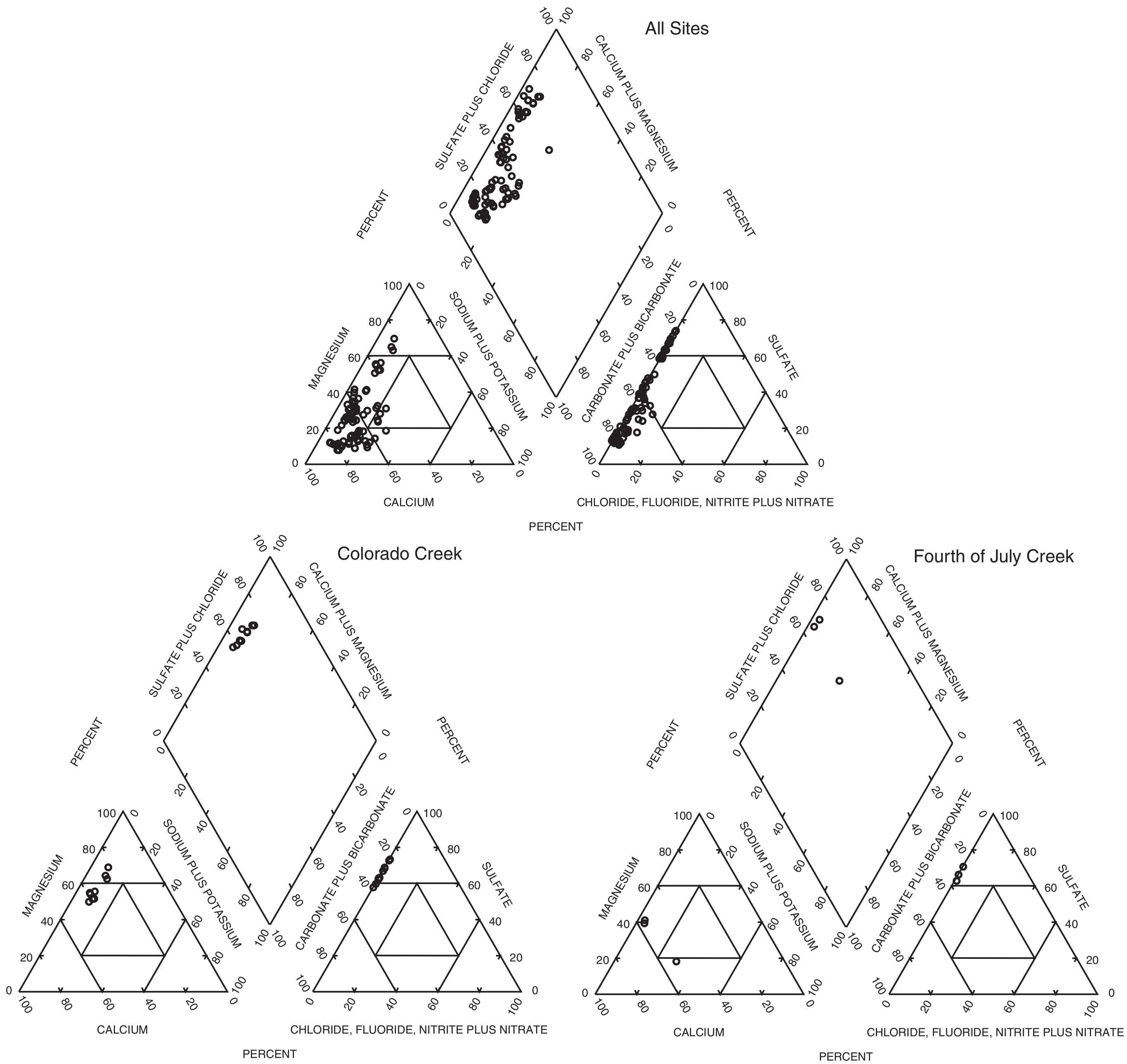

Figure 10. Trilinear diagrams of water samples collected at sites on the south side of Denali National Park and Preserve.

Table 8. Results of regression analysis relating concentrations of dissolved solids and major ions to specific conductance in streamflow samples collected from streams, south side Denali National Park and Preserve, Alaska.

[SC, specific conductance; all equations significant at the 99 percent level; mg/L, milligrams per liter]

Constituent	Regression equation	Coefficient of determination (R^2)	Standard Error (mg/L)
Calcium	0.74 + 0.11 (SC)	0.89	1.77
Magnesium	-0.95 + 0.04 (SC)	0.86	0.84
Sodium	0.34 + 0.01 (SC)	0.61	0.41
Bicarbonate	4.0 + 0.23 (SC)	0.82	5.0
Sulfate	-4.8 + 0.24 (SC)	0.89	3.9
Dissolved Solids	1.23 + 0.46 (SC)	0.94	5.4

Phosphorus is an essential element in the growth of plants and animals. It occurs as organically bound phosphorus or as phosphate. High concentrations of phosphorus in water are not considered to be toxic to human or aquatic life. However, its presence can stimulate the growth of algae in lakes and streams. It was first noted by Sawyer (1947) that nuisance algal conditions could be expected in lakes when concentrations of inorganic nitrogen (NH_3 + NO_2 + NO_3 as N) as low as 0.3 mg/L are present in conjunction with as little as 0.01 mg/L of phosphorus.

Phosphorus concentrations are reported as total phosphorus and dissolved orthophosphate. The orthophosphate ion, PO_4, is the most important form of phosphorus because it is directly available for metabolic use by aquatic plants. Concentrations of total phosphorus and dissolved phosphorus were less than 0.01mg/L for all samples collected at Camp Creek (table 9). At Costello Creek (table 10), concentrations of total phosphorus were greater than 0.01 mg/L but still less than 1.0 mg/L.

Dissolved organic carbon (DOC) is commonly a major pool of organic matter in ecosystems. DOC is defined as organic carbon in the filtrate (dissolved and colloidal phases) that has passed through a 0.45 -*u*m pore-size filter. Generally, DOC is in greater abundance than particulate organic carbon (POC), accounting for approximately 90 percent of the total organic carbon of most waters (Aiken and Cotsaris, 1995). In the aquatic system, the sources of DOC can be categorized as (1) allochthonous—entering the system from a terrestrial watershed, and (2) autochthonous—being derived from biota (algae, bacteria, macrophytes) growing in the water body. Determination of these sources of DOC was not done for this study due to the large volume of water that is required for analysis.

At Camp Creek, concentrations of DOC ranged from 2.9 mg/L to 15.0 mg/L. All POC concentrations were less than 1.0 mg/L (table 9). The DOC concentrations were slightly higher than those for Costello Creek, where concentrations of DOC ranged from 0.62 mg/L to 4.0 mg/L and concentrations of POC were all less than 1.0 mg/L (table 10). These concentrations probably reflect the fact that some of the Camp Creek basin consists of some bogs while most of the Costello Creek Basin consists of rough mountainous lands with a thin soil cover.

Only DOC data were collected at the NPS sites (table 7). Concentrations of DOC were similar to DOC concentrations at Camp Creek and Costello Creek. The relatively low DOC concentrations indicate the absence of a soil layer on the south side of DNPP. The highest values (8.0 mg/L) might indicate some better developed soil layers in these basins.

Organic Compounds

Streambed sediments at Costello Creek above Camp Creek, Camp Creek, and Costello Creek below Camp Creek were collected and analyzed for 65 organic compounds (table 11). Most of these compounds were not found at all three sites. Compounds were detected but the concentrations of most of these compounds were less than the Minimum Reporting Level of 50 ug/kg (tables 12-14). Concentrations of the detected compounds were also compared with the blank sample analyzed at the NWQL. If concentrations of these compounds were found in the blank sample at more than 5 percent of the concentration in the environmental sample, it was assumed that the sample was contaminated (Ed Furlong, USGS, personal communication, 2002). This comparison indicated that certain samples were contaminated with butybenzlphthalate, dibutlyphthalate, phenol, and bis (2-ethylhexyl) phthalate. The only other site that was sampled for organic compounds was Colorado Creek (site number 57, fig. 4). This site was sampled in 1998 and no organic compounds were detected (Frenzel, 2000).

Five organic compounds were detected at Costello Creek above Camp Creek (table 12). Dibenzothiophene was the only compound measured above the MRL and is thought to be naturally present in coal (Merck Index, 1983). Other compounds found at this site are also naturally present (phenanthrene, 2,6 dimethylnapthalene), or found in coal tar, coal tar derivatives, or in polychlorinated biphenols.

Table 9. Nutrient and organic carbon concentrations measured in water samples collected from Camp Creek at mouth near Colorado, Alaska (station 15292302)

[all values in milligrams per liter; $NO_2 + NO_3$, nitrate plus nitrite; E, estimated; <, less than, *, collected by NPS].

Date (mm/dd/yy)	Nitrogen nitrite, dissolved	Nitrogen NO_2 + NO_3, dissolved	Nitrogen ammonia, dissolved	Nitrogen ammonia + organic, total	Nitrogen ammonia + organic, dissolved	Phosphorus, total	Phosphorus, dissolved	Phosphorus, ortho dissolved	Dissolved organic carbon	Particulate organic carbon
07/14/95*	--	--	--	--	--	--	--	--	4.3	--
09/11/95*	--	--	--	--	--	--	--	--	5.7	--
06/02/96*	--	--	--	--	--	--	--	--	5.0	--
09/06/96*	--	--	--	--	--	--	--	--	5.2	--
06/04/99	0.001	<0.005	0.003	0.17	0.17	0.044	0.012	<0.001	3.7	0.40
08/03/99	0.001	<0.005	0.002	E0.10	E0.10	0.005	0.004	0.001	3.6	--
09/20/99	0.001	<0.005	0.007	0.16	0.13	0.004	0.005	<0.001	2.9	<0.2
06/01/00	0.001	0.008	0.014	0.21	0.13	0.032	0.007	<0.001	6.4	0.5
07/11/00	0.004	0.015	0.006	0.15	0.12	0.017	E.003	0.002	3.2	0.4
08/08/00	<0.001	<0.005	0.003	0.12	0.10	E0.004	<0.006	<0.001	15	<0.2
09/07/00	0.001	<0.005	0.008	0.11	E0.10	E0.005	<0.006	<0.001	2.9	<0.2

Table 10. Nutrient and organic carbon concentrations measured in water samples collected from Costello Creek below Camp Creek near Colorado, Alaska (station 15292304)

[all values in milligrams per liter; $NO_2 + NO_3$, nitrite plus nitrate; E, estimated; <, less than, *, collected by NPS].

Date (mm/dd/yy)	Nitrogen nitrite, dissolved	Nitrogen NO_2 + NO_3, dissolved	Nitrogen ammonia, dissolved	Nitrogen ammonia + organic, total	Nitrogen ammonia + organic, dissolved	Phosphorus, total	Phosphorus, dissolved	Phosphorus, ortho dissolved	Dissolved organic carbon	Particulate organic carbon
07/14/95*	--	--	--	--	--	--	--	--	2.8	--
09/11/95*	--	--	--	--	--	--	--	--	4.5	--
06/02/96*	--	--	--	--	--	--	--	--	3.2	--
09/06/96*	--	--	--	--	--	--	--	--	5.1	--
06/04/99	0.001	0.014	0.003	E0.06	E0.10	0.067	0.007	<0.001	2.1	0.3
08/03/99	0.001	0.028	<0.002	0.23	<0.10	0.193	<0.004	0.002	1.0	0.50
09/20/99	0.001	0.044	0.007	0.13	E0.10	0.012	<0.004	0.001	0.90	--
06/01/00	0.002	0.097	0.005	0.16	E0.10	0.039	E0.005	<0.001	4.0	0.34
07/11/00	0.001	0.050	0.003	0.21	E0.10	0.271	<0.006	0.003	0.62	0.58
08/08/00	<0.001	0.020	0.005	<0.10	<0.10	0.025	<0.006	0.003	0.69	<0.2
09/07/00	0.001	0.009	0.004	<0.10	<0.10	<0.008	E0.003	0.001	0.71	<0.2

Table 11. Organic compounds analyzed for detection in bed sediments of Costello Creek above Camp Creek (station 631618149323700), Camp Creek (15292302), and Costello Creek below Camp Creek (15292304)

1,2,4-Trichlorobenzene	Acenaphthene	Fluorene
1,2-Dichlorobenzene	Acenaphthylene	Fluoranthene
1,2-Dimethylnaphthalene	Acridine	Hexachlorobenzene
1,3-Dichlorobenzene	Anthracene	Indeno[1,2,3-*cd*]pyrene
1,4-Dichlorobenzene	Anthraquinone	Isophorone
1,6-Dimethylnaphthalene	Azobenzene	Isoquinoline
1-Methyl-9H-fluorene	Benz[*a*]anthracene	Naphthalene
1-Methylphenanthrene	Benzo[*a*]pyrene	N-Nitrosodiphenylamine
1-Methylpyrene	Benzo[*b*]fluoranthene	N-Nitrosodi-*n*-propylamine
2,2-Biquinoline	Benzo[*c*]cinnoline	Nitrobenzene
2,3,6-Trimethylnaphthalene	Benzo[*ghi*]perylene	Pentachloroanisole
2,4-Dinitrotoluene	Benzo[*k*]fluoranthene	Pentachloronitrobenzene
2,6-Dimethylnapthalene	Butylbenzyl phthalate	Phenanthrene
2,6-Dinitrotoluene	C_8-Alkylphenol	Phenanthridine
2-Chloronaphthalene	Carbazole	Phenol
2-Chlorophenol	Chrysene	Pyrene
2-Ethylnaphthalene	Di-*n*-octyl phthalate	Quinoline
2-Methylanthracene	Dibenz[*a,h*]anthracene	*bis*(2-Chloroethoxy)methane
3,5-Dimethylphenol	Dibenzothiophene	*bis*(2-Chloroethyl)ether
4-Bromophenylphenylether	Dibutylphthalate	*bis*(2-ethylhexyl) phthalate
4-Chloro-3-methylphenol	Diethyl phthalate	*p*-Cresol
4H-cyclopenta[*def*]phenanthrene	Dimethyl phthalate	

Camp Creek, the mined watershed, had seven detections of organic compounds (table 13). Phenanthrene, which is naturally present in coal (Parker, 1984), was detected at the MRL and the remainder of the compounds were detected below the MRL. Concentrations of all compounds were well below the criteria for aquatic life set by the U.S. Environmental Protection Agency (1996). In addition to phenanthrene, the compounds 1,6-Dimethylnapthalene, 2,3,6-Trimethynapthalene, and 1-Methylphenanthrene, are probably naturally occurring and not due to mining activities. Two of these compounds were detected at Costello Creek above Camp Creek, another indicator that some of the organic compounds may be naturally occurring.

The two organic compounds detected at Costello Creek below Camp Creek (table 14), phenanthrene and *p*-Cresol, are thought to occur naturally. Thus, it is unlikely, any organic compounds are present in Costello Creek due to mining activities at the Dunkle Mine.

Trace Elements

Samples of the water column, slimy sculpin, and the streambed were collected and analyzed for trace elements at Camp Creek and Costello Creek below Camp Creek. Samples of the streambed and slimy sculpin were collected for trace elements at Costello Creek above Camp Creek in 1998. Water-column samples were analyzed for 42 trace elements, bed sediments for 39 trace elements, and sculpin for 22 trace elements.

For the water-column samples, concentrations of 21 of the 42 trace elements were less than or equal to 1.0 *u*g/L at Camp Creek and concentrations of 18 of the 42 trace elements were less than or equal to 1.0 *u*g/L at Costello Creek below Camp Creek (tables 15-16). Two trace elements, total aluminum and iron, showed a strong correlation with suspended sediment that suggests these two elements are adsorbed onto the sediment (table 17). In comparing the

Table 12. Concentrations of organic compounds detected in bed sediments of Costello Creek above Camp Creek at mouth near Colorado, Alaska (station 6316181493237)

[µg/kg, micrograms per kilogram; E, estimated]

Compound	Concentration (µg/kg)	Possible Source
Chrysene	E20	Coal tar and exhaust from gasoline engines
Dibenzothiophene	80	Natural
Phenanthrene	E30	Natural
Pyrene	E10	Coal tar
2,6 Dimethylnapthalene	E10	Natural

Table 13. Concentrations of organic compounds detected in bed sediments of Camp Creek at mouth near Colorado, Alaska (station 15292302)

[µg/kg, micrograms per kilogram; E, estimated]

Compound	Concentration (µg/kg)	Possible Sources
1,6-Dimethylnaphthalene	E20	Naturally occurring
2,3,6-Trimethylnaphthalene	E20	Naturally occurring
1-Methylphenanthrene	E10	Naturally occurring
1-Methylpyrene	E10	Coal tar derivative
Fluoranthene	E20	Coal tar derivative
Phenanthrene	50	Naturally occurring
Pyrene	E20	Coal tar derivative

concentrations of the dissolved trace elements to published or know values of other studies (table 18), concentrations of all trace elements were within the normal ranges with the exception of iron for Camp Creek and strontium for Costello Creek. Higher values of iron in Camp Creek may be due to the presence of a soil layer in its basin and the higher values of strontium in Costello Creek may be due to the presence of sedimentary rocks in its basin. In comparing the trace element concentrations with known water-quality standards that have been established for the protection of aquatic life (table 19), no concentrations of the trace elements exceeded either acute or chronic concentrations.

With the exception of arsenic, iron and selenium, sculpin from both sites on Costello Creek had higher concentrations of trace elements than at Camp Creek (table 20). Only selenium concentrations in slimy sculpin appear to be at levels of potential concern. Typical selenium concentrations in fish at background sites are less than 2 *u*g/g (U.S. Department of the Interior, 1998), whereas selenium concentrations at the three sites were equal to or greater than 6.7 *u*g/g. Whole-body selenium concentrations of 4 to 6 *u*g/g were estimated as the threshold for reproductive impairment in sensitive species such as salmon (U.S. Department of the Interior, 1998). However, slimy sculpin may bioaccumulate selenium to a greater degree than do salmonoids.

Streambed sediments of Camp Creek, Costello Creek above Camp Creek, and Costello Creek below Camp Creek were collected and analyzed for 39 trace elements in 1998 and 1999 (table 21). Streambed sediments were also collected at 12 of the NPS sites during September, 2000 and analyzed for the same trace elements. These sites were chosen so a good spatial distribution was obtained throughout the south side of DNPP.

In reviewing the literature on criteria for bed sediments, the focus has been limited to 9 trace elements: arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc. Trace-element concentrations in streambed sediments were compared with those of previous studies (table 22). Gilliom and others (1998) determined national median concentrations (in micrograms per gram, dry weight) for these elements. As part of the NAWQA program, a NAWQA data base has been established where users may retrieved water-quality data from other NAWQA study units based on criteria such as land use. From this data base, trace element data for basins listed as ‘mined’ were retrieved and the median concentration values determined. The Canadian Council of Ministers of the Environment (1999) has established guidelines for some trace elements in unsieved streambed sediment. These guidelines use two assessment values: a lower value, called the “interim freshwater sediment quality guideline” (ISQG), is the concentration below which adverse effects are expected to occur rarely. The upper value, called the “probable effect level” (PEL), is the concentration above which adverse effects are expected to occur frequently (table 22). Because trace-element samples for the NAWQA program are from sediments finer than 0.063 mm where concentrations tend to be greatest, comparisons with the Canadian guidelines may overestimate the effects on aquatic organisms (Deacon and Stephens, 1998). However, it was felt that the PEL would be useful for comparative purposes when applied to the finer than 0.063 mm size fraction sediment samples analyzed for this study.

Table 14. Concentrations of organic compounds detected in bed sediments of Costello Creek below Camp Creek near Colorado, Alaska (station 15292304)

[µg/kg, micrograms per kilogram; E, estimated]

Compound	Concentration (µg/kg)	Possible Sources
Phenanthrene	E10	Naturally occurring
p-Cresol	E9.2	Coal tar derivative

Table 15. Trace element concentrations measured in water samples collected from Camp Creek at mouth near Colorado, Alaska (station 15292302)

[all values in micrograms per liter; E, estimated; <, less than; --, no data]

Date (mm/dd/yy)	Aluminum, total	Aluminum, dissolved	Antimony, total	Antimony, dissolved	Arsenic, total	Arsenic, dissolved	Barium, total	Barium, dissolved	Berrylium, total
08/03/99	50	<14	<1	<1	2	<1	--	30	<4
06/01/00	308	52	<1	<1	E1	E.6	29	24	<5
07/11/00	339	16	<1	<1	E2	E.8	28	23	<5
08/08/00	42	18	<1	<1	<3	0.9	28	30	<6
09/07/00	44	14	<1	<1	<3	E.8	29	30	<5

Date	Berrylium, dissolved	Boron, dissolved	Cadmium, total	Cadmium, dissolved	Chromium, total	Chromium, dissolved	Cobalt, total	Cobalt, dissolved	Copper, total
08/03/99	<1	--	<1	<1	<1	--	<1	<1	<12
06/01/00	<1	<12	<1	<1	<1	<0.8	<2	<1	<20
07/11/00	<1	<12	<1	<1	<1	<0.8	<2	<1	<20
08/08/00	<1	<12	<1	<1	<0.8	<0.8	<2	<1	<20
09/07/00	<1	<12	<1	<1	<0.8	<0.8	<2	<1	<20

Date	Copper, dissolved	Iron, total	Iron, dissolved	Lead, total	Lead, dissolved	Lithium, total	Lithium, dissolved	Manganese, total	Manganese, dissolved
08/03/99	<1	180	79	<1	<1	<10	--	4	2.1
06/01/00	1	1060	230	<1	<1	<10	M	36	10
07/11/00	<1	630	80	<1	<1	M	1	9	2.6
08/08/00	<1	200	130	<1	<1	<10	1	4	3.6
09/07/00	<1	180	110	<1	<1	<10	M	4	3.4

Date	Mercury, total	Molybdenum, total	Molybdenum, dissolved	Nickel, total	Nickel, dissolved	Selenium, total	Selenium, dissolved	Silver, total	Silver, dissolved
08/03/99	--	<1	<1	<1	<1	<1	<1	<1	<1
06/01/00	<0.3	<1	<1	E1	1	<3	<0.7	<1	<1
07/11/00	<0.3	1	<1	E2	<1	<3	<0.7	<1	<1
08/08/00	<0.3	<1	<1	<2	<1	<3	<0.7	<1	<1
09/07/00	<0.3	<1	<1	E1	<1	<3	<0.7	<1	<1

Date	Strontium, total	Strontium, dissolved	Thallium, dissolved	Vanadium, dissolved	Zinc, total	Zinc, dissolved
08/03/99	60	--	--	--	<40	<1
06/01/00	38	40	<0.9	<1	<31	5
07/11/00	48	47	<0.9	<1	<31	3
80/08/00	69	69	<0.9	<1	<31	6
09/07/00	67	67	<0.9	<1	<31	3

Table 16. Trace element concentrations measured in water samples collected from Costello Creek below Camp Creek near Colorado, Alaska (station 15292304)

[all values in micrograms per liter; E, estimated; <, less than, --, no data]

Date (mm/dd/yy)	Aluminum, total	Aluminum, dissolved	Antimony, total	Antimony, dissolved	Arsenic, total	Arsenic, dissolved	Barium, total	Barium, dissolved	Berrylium, total
08/03/99	5600	13	<1.0	<1.0	5.0	<1.0	100	35	<4.0
06/01/00	566	29	<1.0	<1.0	<3.0	0.9	38	29	<5.0
07/11/00	4960	25	<1.0	<1.0	6.0	1.3	93	27	<5.0
08/08/00	504	7	<1.5	<1.0	E2.0	1.6	41	35	<5.0
09/07/00	41	4	<1.0	<1.0	E2.0	1.7	42	45	<5.0

Date	Berrylium, dissolved	Boron, dissolved	Cadmium, total	Cadmium, dissolved	Chromium, total	Chromium, dissolved	Cobalt, total	Cobalt, dissolved	Copper, total
08/03/99	<1.0	--	<1.0	<1.0	12	--	3.0	<1.0	E11
06/01/00	<1.0	E9.0	<0.1	<1.0	1.0	<0.8	<2.0	<1.0	<20
07/11/00	<1.0	<12	<0.1	<1.0	15	<0.8	4.0	<1.0	E14
08/08/00	<1.0	E8.0	<0.1	<1.0	2.0	<0.8	<2.0	<1.0	<20
09/07/00	<1.0	12	<0.1	<1.0	<1.0	<0.8	<2.0	<1.0	<20

Date	Copper, dissolved	Iron, total	Iron, dissolved	Lead, total	Lead, dissolved	Lithium, total	Lithium, dissolved	Manganese, total	Manganese, dissolved
08/03/99	<1.0	6800	<10.0	3.0	<1.0	E10	--	130	3
06/01/00	<1.0	1360	100	<1.0	<1.0	<7.0	1.8	36	8
07/11/00	<1.0	8950	<10	4.0	<1.0	10	2.3	167	6
08/08/00	<1.0	1010	10	<1.0	<1.0	<7.0	3.2	19	2
09/07/00	<1.0	80	E10	<1.0	<1.0	E3.4	3.5	E2	3

Date	Mercury, total	Molybdenum, total	Molybdenum, dissolved	Nickel, total	Nickel, dissolved	Selenium, total	Selenium, dissolved	Silver, total	Silver, dissolved
08/03/99	--	<1.0	1.1	14	<1.0	2.0	<1	<1.0	<1.0
06/01/00	<.3	<1.0	<1.0	3.0	1.0	<3.0	E.6	<1.0	<1.0
07/11/00	<.3	<1.0	<1.0	19	2.0	E2.0	0.9	<1.0	<1.0
08/08/00	<.3	<1.0	<1.0	E2	<1.0	E2.0	1.2	<1.0	<1.0
09/07/00	<.3	2.0	1.0	<2.0	<1.0	E3.0	1.6	<1.0	<1.0

Date	Strontium, Total	Strontium, Dissolved	Thallium, Dissolved	Vanadium, Dissolved	Zinc, Total	Zinc, Dissolved
08/03/99	210	--	--	--	E30	<1.0
06/01/00	112	114	<0.9	<1	<31	4.0
07/11/00	150	150	<0.9	<1	33	4.0
08/08/00	194	201	<0.9	<1	<31	<1.0
09/07/00	228	242	<0.9	<1	<31	2.0

Table 17. Correlation coefficients for aluminum, iron, and suspended sediment in Camp Creek and Costello Creek below Camp Creek near Colorado, Alaska.

	Aluminum	Iron	Suspended Sediment
Camp Creek at mouth near Colorado			
Aluminum	1.00		
Iron	0.89	1.00	
Suspended Sediment	0.91	0.99	1.00
Costello Creek below Camp Creek near Colorado			
Aluminum	1.00		
Iron	0.96	1.00	
Suspended Sediment	0.96	0.99	1.00

MacDonald and others (2000) established sediment quality guidelines (SQGs) for 7 trace elements and Van Derveer and Canton (1997) established guidelines for selenium. These guidelines use two concentrations for a given trace element; the threshold effect concentration (TEC) and the probable effect concentration (PEC) (table 22). The TEC is the concentration below which sediment-dwelling organisms are unlikely to be adversely affected, and the PEC is the concentration above which toxicity is likely. In addition, MacDonald and others (2000) developed a Mean PEC Quotient (table 23) which is the toxicity of the combined trace element concentrations. This value is determined by summing the concentrations of all the trace elements analyzed and dividing by the number of elements. A quotient value below 0.5 indicates the absence of toxicity and a value greater than 0.5 indicates the presence of toxicity. MacDonald and others determined the PEC Quotient based on normalized organic carbon values.

Table18. Summary of dissolved trace element concentrations from previous studies compared to ranges of dissolved trace element concentrations from Camp Creek and Costello Creek near Colorado, Alaska

[all values in µg/l]

Element	Martin and Whitfield (1983)	Meybeck (1988)	Hem (1985)	Camp Creek	Costello Creek
Aluminum	50	40 +- 20	--	<14 - 52	4 - 29
Antimony	1	--	0.1-1	<1	<1
Arsenic	1.7	1+- 0.5	0.1-1	<1	0.9 - 1.7
Barium	60	--	10	23 - 30	27 - 45
Beryllium	--	--	0.1	<1	< 1
Boron	18	30 +- 20	--	<12	E8.0 - 12
Cadmium	0.02	--	0.1-1	<1	< 1.0
Chromium	1	0.8 +- 0.3	0.1-1	<0.8	< 0.8
Cobalt	0.2	0.1+- 0.05	0.1	<1	< 2.0 - 4.0
Copper	1.5	2+-1	1-10	<1 - 1	< 1.0
Iron	40	50+-30	--	79 - 230	<10 - 100
Lead	0.1	--	.1-1	<1	< 1.0
Lithium	12	--	--	1	E3.4 - 10
Manganese	8.2	10+-5	--	2.1 - 10	2 - 8
Mercury	--	--	0.1	--	--
Molybdenum	0.5	0.8+- 0.4	0.1-1	<1	<1 - 1.1
Nickel	0.5	0.4+-0.3	0.1-1	<1 - 1	<1.0 - 2.0
Selenium	--	--	0.1	<1	E2.0 - < 3.0
Silver	0.3	0.4+-0.2	0.1	<1	< 1.0
Strontium	60	--	--	40 - 69	114 - 242
Vanadium	1	--	1	<1	<1
Zinc	30	10+-5	1-10	<1 - 6	<1.0 - 4.0

Table 19. Dissolved concentrations of selected trace elements that have established water-quality standards for protection of aquatic life (Smith and Huyck, 1999)

[values in micrograms per liter]

Trace element	Acute	Chronic
Aluminum	750	87
Antimony	9,000	1,600
Arsenic	360	190
Beryllium	130	5.3
Cadmium	3.9	1.1
Chromium (VI)	16	11
Copper	18	12
Iron		1,000
Lead	82	3.2
Mercury	2.4	0.012
Nickel	1,400	160
Selenium	20	5
Silver	4.1	0.12
Thallium	1,400	40
Zinc	120	110

Comparison of the concentrations of the bed sediments of the 9 trace elements with median values from Gilliom and others (1998) and the NAWQA data base (http://water.usgs.gov/nawqa/data, accessed July 2002) indicated that arsenic and nickel concentrations at Camp Creek and Costello Creek are higher than the median values found in other NAWQA study units (table 22). Most other streams on the south side of DNPP also had higher

Table 20. Trace element concentrations measured in fish tissue samples collected from Costello Creek above Camp Creek (station 6316131493142), Camp Creek (station 15292302), and Costello Creek below Camp Creek near Colorado, Alaska (station 15292304)

[all values in micrograms per gram dry weight, <, less than]

Trace Element	Costello above Camp Creek near Colorado	Camp Creek at mouth near Colorado	Costello Creek below Camp Creek near Colorado
Aluminum	260	70	150
Antimony	<0.3	<0.2	<0.2
Arsenic	1.2	1.6	1.1
Barium	19	13	27
Berylium	<0.3	<0.2	<0.2
Boron	1.9	0.3	1.0
Cadmium	0.4	0.2	0.4
Chromium	2.8	2.0	3.6
Cobalt	1.2	0.8	1.1
Copper	4.6	3.2	6.1
Iron	450	1,000	330
Lead	<0.3	<0.2	0.3
Manganese	27	17	38
Mercury	0.1	M	0.1
Molybdenum	<0.3	<0.2	<0.2
Nickel	1.5	1.0	1.6
Selenium	8.5	9.6	6.7
Silver	<0.3	<0.2	<0.2
Strontium	110	62	180
Uranium	<0.3	<0.1	<0.2
Vanadium	1.4	0.8	1.1
Zinc	120	62	240

concentrations of these elements, suggesting these are naturally occurring elements and not related to mining activities. In addition to arsenic and nickel, concentrations of copper at Costello Creek above and below Camp Creek, exceeded the ISQG limits. Concentrations of copper at six other sites on the south side of DNPP also exceeded the ISQG limit. Arsenic concentrations exceed the PEL at Camp Creek, Costello Creek (above and below Camp Creek) and at seven other sites.

Comparison of the concentrations of the trace elements at Camp Creek with the TEC, PEC, and mean PEC quotient, indicated that concentrations of arsenic, chromium, mercury, and nickel exceeded the TEC and arsenic exceed the PEC. However, the mean PEC quotient for Camp Creek was only slightly above the threshold of 0.5. Costello Creek above Camp Creek and Costello Creek below Camp Creek both had concentrations of arsenic, chromium, mercury, and nickel that exceeded the TEC and concentrations of chromium and nickel that exceeded the PEC. The toxicity quotients for both sites were greater than one. As MacDonald and others (2000) noted, sites containing relatively low concentrations of organic carbon such as Costello Creek have higher potential toxicity.

There were many similarities in concentrations of trace elements in the 12 streams compared to Costello and Camp Creeks. Concentrations of arsenic, chromium, and nickel exceeded either the TEC or PEC (table 23). In addition, concentrations of lead at four sites exceeded the TEC or PEC and concentrations of cadmium exceed the TEC at one site. Most mean PEC quotients indicated toxicity and those values below or near 0.5 had relatively high percentages of organic carbon.

CLUSTER AND MULTIDISCRIMINANT ANALYSIS OF TRACE ELEMENTS IN BED SEDIMENTS

Cluster analysis was developed as a means of classifying objects into homogeneous groups on the basis of some measure or set of measures describing the objects. It is a multivariate statistical technique that separates data into groups or clusters that are both homogeneous and distinct from other groups (Davis, 1986). The type clustering used in this study is known as *k*-means clustering, in which *k* points characterized by *m* variables are designated (either by the user or arbitrarily by the program) as initial centroids. The number of observations are calculated, and the closest or most similar observations are clustered with the nearest centroids. New centroids are then calculated and the process iterates exactly like a hierarchical procedure. This clustering method divides candidate basins into groups by maximizing the between-cluster variation and minimizing the within-cluster variation.

Multiple Discriminant Analysis (MDA) is used as a multivariate classification tool to decide in which of several groups a response is most likely to belong. MDA determines which variables ‘discriminate’ between two or more naturally occurring groups or which variables are the best predictors. The MDA analysis used in this study is known as forward stepwise analysis. In stepwise discriminant analysis, a model of discrimination is built step-by-step. Statistical software will review all variables and evaluate which one will contribute most to the discrimination between groups. That variable will then be included in the model and the process is repeated. Probabilities of being in each group are computed as a function of one or more continuous variables. The group having the highest probability is selected as the group most likely of being in a particular region.

These two statistical techniques were tested with the trace element streambed sediment data to determine if there are differences or similarities among these watersheds. For the cluster analysis, a dendrogram (fig. 11) was constructed to determine whether the clusters were good in terms of their separability. Dendrograms order the clusters relative to each other using the multidimensional distance separating the classes in attribute space. A good cluster should have little overlap between the clusters in multivariate space. If the dendrogram indicates clusters with identical means, the clusters are often combined. The cluster analysis of the trace element data indicated that the watersheds could be grouped into two main clusters (fig. 11). The first cluster includes 5 sites and the second cluster includes 11 sites. The first group could be generally characterized as having some percentage of their basins consisting of Tertiary rocks, low values of arsenic, chromium, copper, and organic carbon while the second cluster consists of those basins with a low percentage of tertiary rocks and high values of the trace elements and organic carbon.

To test whether the cluster analysis was valid, the data were analyzed using multiple discriminant techniques. The results of the first forward stepwise analysis, using the trace elements as the variables, indicated that iron and tantalum were the most significant variables. Although the classification based on these two variables is good, it is unclear what is the basis for the classification. Thus, another forward stepwise analysis was tested using only basin characteristics. The resulting discriminant function showed good classification based on the following variables: drainage area, glacier area, tertiary deposits, cretaceous deposits, and quaternary deposits. Using this discriminant function assigned the sites to the same groups as the cluster analysis.

Table 21. Trace element concentrations measured in bed sediment samples collected from sites on the south side of Denali National Park and Preserve, Alaska

[all values in micrograms per gram, dry weight; <, less than]

Site number (figure 5)	Station Name	Aluminum	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cadmium	Cerium
57	Colorado Creek near Colorado	6.7	4.2	44	970	2.5	<1	0.5	42
58	Costello Creek near Colorado	7.4	2.4	23	1200	1.9	<1	0.3	49
95	Camp Creek at mouth near Colorado	6.6	3.1	49	980	1.8	<1	0.5	64
96	Costello Creek below Camp Creek near Colorado	6.3	2.5	25	1400	1.8	<1	0.3	45
97	Crystal Creek at mouth near Talkeetna	7.3	0.1	10	920	2.7	<1	0.2	400
98	Coffee River above Crystal Creek near Talkeetna	7.3	0.1	9.1	990	3.8	<1	0.2	250
99	Bear Creek near Talkeetna	6.7	2.2	42	900	1.4	<1	0.5	66
100	Wildhorse Creek near Talkeetna	7.0	2.0	56	1000	1.6	<1	1.9	33
101	Long Creek near Talkeetna	5.1	1.2	46	690	1.3	<1	0.2	44
102	Hidden Creek near Talkeetna	8.2	<0.1	3.3	550	2.5	<1	<.1	62
103	Snowslide Creek at mouth near Talkeetna	8.5	0.5	1.7	1200	3.9	<1	0.4	130
104	Cripple Creek above Snowslide Creek near Talkeetna	6.6	0.2	8.7	1000	2.5	<1	0.3	120
105	Cascade Creek at mouth near Talkeetna	6.8	1.2	88	1000	1.9	<1	0.2	110
106	Fourth of July Creek at mouth near Talkeetna	5.6	1.3	26	1000	1.7	<1	0.3	64
107	Morris Creek at mouth near Talkeetna	5.1	3.1	30	1000	1.2	<1	0.2	32
108	Kichatna River above Morris Creek near Talkeetna	7.4	0.8	16	480	4.0	1.0	<0.1	140
		Chromium	Cobalt	Copper	Europium	Gallium	Gold	Holmium	Iron
57	Colorado Creek near Colorado	220	23	59	1	14	<1	1	4.2
58	Costello Creek near Colorado	170	20	64	2	16	<1	1	4.7
95	Camp Creek at mouth near Colorado	110	16	35	1	16	<1	<1	3.3
96	Costello Creek below Camp Creek near Colorado	140	18	55	1	14	<1	<1	4.2
97	Crystal Creek at mouth near Talkeetna	24	3	16	1	22	<1	3	1.7
98	Coffee River above Crystal Creek near Talkeetna	10	2	10	1	21	<1	2	1.1
99	Bear Creek near Talkeetna	140	26	59	1	17	<1	<1	4.6
100	Wildhorse Creek near Talkeetna	120	19	48	<1	16	<1	<1	3.6
101	Long Creek near Talkeetna	79	10	26	1	13	<1	<1	4.1
102	Hidden Creek near Talkeetna	3.0	<1	3	<1	15	<1	<1	0.40
103	Snowslide Creek at mouth near Talkeetna	10	2	11	1	19	<1	2	1.1
104	Cripple Creek above Snowslide Creek near Talkeetna	68	8	26	1	16	<1	2	2.2
105	Cascade Creek at mouth near Talkeetna	87	14	48	2	16	<1	1	3.4
106	Fourth of July Creek at mouth near Talkeetna	150	18	49	1	14	<1	<1	3.9
107	Morris Creek at mouth near Talkeetna	150	20	47	<1	14	<1	<1	4.2
108	Kichatna River above Morris Creek near Talkeetna	29	4	13	<1	21	<1	1	1.3
		Lanthanum	Lead	Lithium	Manganese	Mercury	Molybdenum	Neodymium	Nickel
57	Colorado Creek near Colorado	21	15	66	770	0.18	1.1	21	130
58	Costello Creek near Colorado	26	16	70	710	0.23	1.0	26	98
95	Camp Creek at mouth near Colorado	31	27	40	500	0.24	1.1	29	42
96	Costello Creek below Camp Creek near Colorado	23	18	50	680	0.16	1.2	24	70
97	Crystal Creek at mouth near Talkeetna	190	20	48	530	0.02	1.0	180	11
98	Coffee River above Crystal Creek near Talkeetna	120	22	46	330	<0.02	0.6	110	6
99	Bear Creek near Talkeetna	36	17	47	1200	0.03	1.0	31	81
100	Wildhorse Creek near Talkeetna	18	17	37	1600	0.08	1.6	16	56
101	Long Creek near Talkeetna	22	10	38	490	0.04	1.3	21	32

Table 21. Trace element concentrations measured in bed sediment samples collected from sites on the south side of Denali National Park and Preserve, Alaska (Continued)

[all values in micrograms per gram, dry weight; <, less than]

Site number (figure 5)	Station Name	Lanthanum	Lead	Lithium	Manganese	Mercury	Molybdenum	Neodymium	Nickel
102	Hidden Creek near Talkeetna	31	25	57	240	<0.02	<0.5	27	<2
103	Snowslide Creek at mouth near Talkeetna	71	76	75	340	<0.02	0.9	68	6
104	Cripple Creek above Snowslide Creek near Talkeetna	62	20	43	530	<0.02	1.1	58	37
105	Cascade Creek at mouth near Talkeetna	58	13	37	1100	<0.02	1.2	48	49
106	Fourth of July Creek at mouth near Talkeetna	34	16	51	1600	0.02	1.1	29	80
107	Morris Creek at mouth near Talkeetna	16	14	47	1600	0.07	1.2	15	94
108	Kichatna River above Morris Creek near Talkeetna	76	33	60	400	0.02	0.5	66	17
		Niobium	Scandium	Selenium	Silver	Strontium	Tantalum	Thalium	Thorium
57	Colorado Creek near Colorado	8	15	0.7	0.5	140	1	<1	6
58	Costello Creek near Colorado	8	17	0.7	0.5	150	1	<1	8
95	Camp Creek at mouth near Colorado	14	14	0.5	0.8	120	<1	<1	8
96	Costello Creek below Camp Creek near Colorado	9	14	0.7	0.4	130	<1	<1	7
97	Crystal Creek at mouth near Talkeetna	22	14	0.6	0.3	140	2	<1	63
98	Coffee River above Crystal Creek near Talkeetna	23	8	0.1	0.3	130	2	1	42
99	Bear Creek near Talkeetna	7	15	0.9	0.1	170	<1	<1	9
100	Wildhorse Creek near Talkeetna	7	15	5.2	0.2	200	<1	<1	6
101	Long Creek near Talkeetna	9	10	1.7	0.1	190	<1	<1	6
102	Hidden Creek near Talkeetna	7	<2	<0.1	<0.1	120	1	1	15
103	Snowslide Creek at mouth near Talkeetna	12	5	0.1	0.2	260	1	1	24
104	Cripple Creek above Snowslide Creek near Talkeetna	12	8	0.3	0.2	180	1	<1	20
105	Cascade Creek at mouth near Talkeetna	11	13	0.6	0.1	340	<1	<1	16
106	Fourth of July Creek at mouth near Talkeetna	12	13	0.8	0.2	160	<1	<1	10
107	Morris Creek at mouth near Talkeetna	11	12	1.2	0.2	110	<1	<1	7
108	Kichatna River above Morris Creek near Talkeetna	16	5	0.2	0.2	69	2	1	37
		Tin	Titanium	Uranium	Vanadium	Ytterbium	Yttrium	Zinc	
57	Colorado Creek near Colorado	2	0.5	3.4	150	2	19	150	
58	Costello Creek near Colorado	2	0.5	3.1	170	2	18	140	
95	Camp Creek at mouth near Colorado	2	0.4	3.4	140	2	19	140	
96	Costello Creek below Camp Creek near Colorado	2	0.3	2.4	170	1	15	130	
97	Crystal Creek at mouth near Talkeetna	3	0.25	22	31	6	75	68	
98	Coffee River above Crystal Creek near Talkeetna	4	0.14	12	13	5	56	56	
99	Bear Creek near Talkeetna	2	0.2	3.3	150	2	14	150	
100	Wildhorse Creek near Talkeetna	2	0.2	13	130	1	13	170	
101	Long Creek near Talkeetna	2	0.2	3.2	96	2	18	80	
102	Hidden Creek near Talkeetna	5	0.1	7.8	5	1	15	16	
103	Snowslide Creek at mouth near Talkeetna	5	0.2	18	15	4	51	92	
104	Cripple Creek above Snowslide Creek near Talkeetna	3	0.3	9.8	57	3	39	80	
105	Cascade Creek at mouth near Talkeetna	2	0.3	6.8	100	3	34	95	
106	Fourth of July Creek at mouth near Talkeetna	2	0.4	4.3	130	2	16	130	
107	Morris Creek at mouth near Talkeetna	2	0.3	2.7	140	2	15	150	
108	Kichatna River above Morris Creek near Talkeetna	4	0.1	19	32	3	31	63	

Table 22. Concentrations of selected trace elements in bed materials from various studies

[values in micrograms per gram; --, no data]

Trace element	Gilliom and others (1998)[1]	NAWQA Warehouse[2]	Interim Freshwater Sediment Quality Guideline[3](TEL)	Probable Effect Level[3] (PEL)	Threshold Effect Concentration (TEC)[4]	Probable Effect Concentration (PEC)[4]	Median values for study
Arsenic	6.4	13.0	5.9	17.0	9.8	33.0	26
Cadmium	0.4	0.9	0.6	3.5	0.99	5.0	0.3
Chromium	62	68.5	37.3	90	43.4	111	18
Copper	26	36	35.7	197	31.6	149	41
Lead	24	41.5	35.0	91.3	35.8	128	18
Mercury	0.06	0.08	0.17	0.486	0.18	1.06	0.07
Nickel	25	38	--	--	22.7	48.6	49
Selenium	0.7	0.8	--	--	[5]2.5	[5]4.0	0.6
Zinc	110	235	123	315	121	459	86

[1]Median values
[2] Median values
[3]Canadian Council of Ministers of the Environment (1995)
[4]MacDonald and others (2000)
[5]VanDerveer and Canton (1997)

Table 23. Concentrations trace elements, percent organic carbon, and mean PEC quotient for sites on south side of Denali National Park and Preserve, Alaska

[values in micrograms per gram; bold indicates values exceeds TEC or PEC when normalized for organic carbon content; value exceeds 0.5 for PEC quotient)

Site number (figure 5)	Station Name	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Zinc	Organic Carbon (percent)	Mean PEC quotient
57	Colorado Creek near Colorado	**44**	0.5	**220**	59	15	0.18	**130**	0.7	150	0.52	**1.71**
58	Costello Creek near Colorado	**23**	0.3	**170**	64	16	0.23	**98**	0.7	140	0.46	**1.46**
95	Camp Creek at mouth near Colorado	**49**	0.5	**110**	35	27	0.24	**42**	0.5	140	1.00	**0.55**
96	Costello Creek below Camp Creek near Colorado	**25**	0.3	**140**	55	18	0.16	**70**	0.6	130	0.47	**1.19**
97	Crystal Creek at mouth near Talkeetna	10	0.2	24	16	20	0.02	11	0.6	68	0.80	0.19
98	Coffee River above Crystal Creek near Talkeetna	**9.1**	0.2	**10**	10	**22**	<0.02	**6**	0.1	56	0.08	**1.39**
99	Bear Creek near Talkeetna	**42**	0.5	**140**	59	17	0.03	**81**	0.9	150	1.2	**0.54**
100	Wildhorse Creek near Talkeetna	56	1.9	120	48	17	0.08	56	5.2	170	6.9	0.09
101	Long Creek near Talkeetna	46	0.2	79	26	10	0.04	32	1.7	80	7.1	0.06
102	Hidden Creek near Talkeetna	3.3	<0.1	3	3	**25**	<0.02	<2	<1	16	0.09	**0.53**
103	Snowslide Creek at mouth near Talkeetna	1.7	**0.4**	**10**	11	**76**	<0.02	**6**	0.1	92	0.07	**2.17**
104	Cripple Creek above Snowslide Creek near Tal-keetna	8.7	0.3	**68**	26	20	<0.02	**37**	0.3	80	0.53	**0.52**
105	Cascade Creek at mouth near Talkeetna	**88**	0.2	**87**	48	13	<0.02	**49**	0.6	95	0.36	**1.78**
106	Fourth of July Creek at mouth near Talkeetna	**26**	0.3	**150**	49	16	0.02	**80**	0.8	130	0.57	**1.01**
107	Morris Creek at mouth near Talkeetna	**30**	0.2	**150**	47	14	0.07	**94**	1.2	150	0.49	**1.29**
108	Kichatna River above Morris Creek near Talkeetna	**16**	<0.1	**29**	13	**33**	0.02	**17**	0.2	63	0.11	**1.82**

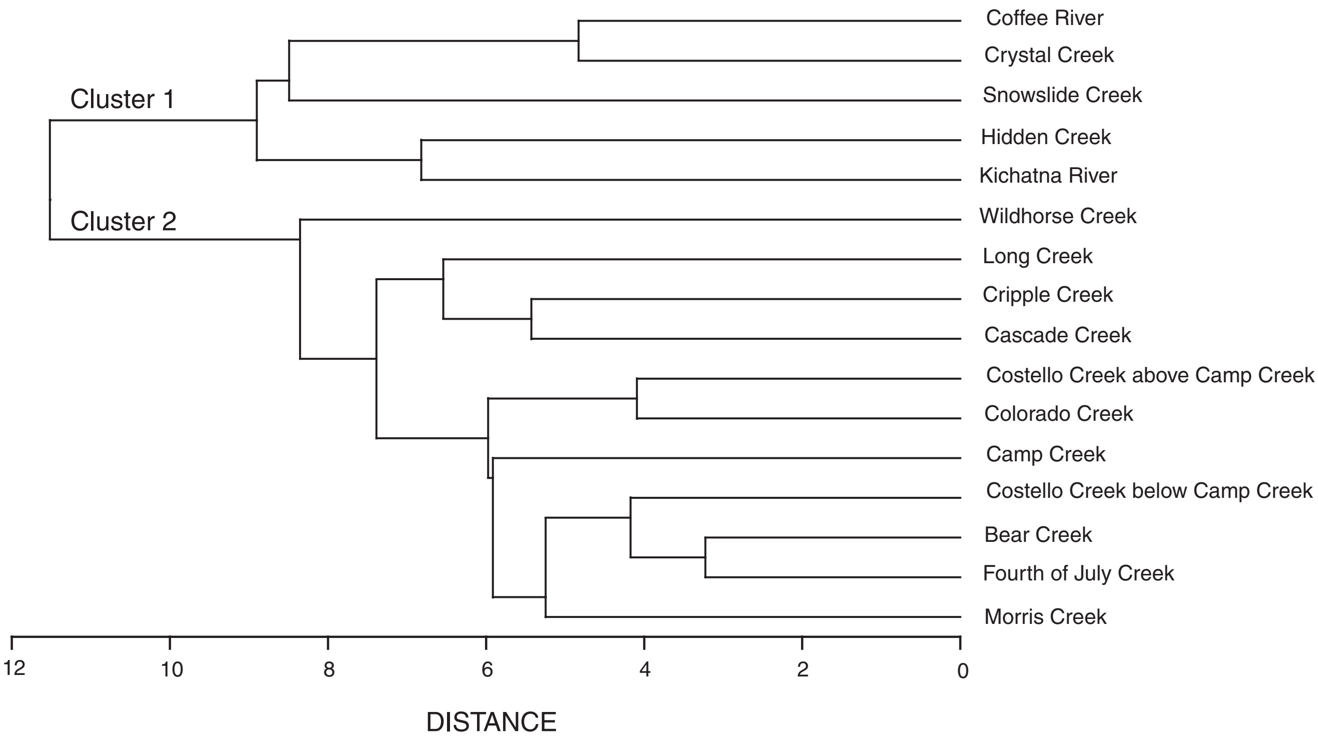

Figure 11. Dendrograms of the cluster regions of sites with trace element bed sediment data.

Thus, not only did the MDA validate the cluster analysis, but the resulting discriminant function could be used to assign a basin to one of the two clusters based upon its basin characteristics.

PHYSICAL HABITAT AND BIOLOGY OF CAMP CREEK AND COSTELLO CREEK

Physical Habitat

Costello Creek is larger and steeper than Camp Creek. The study reach at Costello Creek had a mean width of 48.6 feet, a mean depth of 1.3 feet, a discharge of 104 ft^3/s, and a steep gradient. The study reach at Camp Creek had a mean width of 21.1 feet, a mean depth of 0.7 feet, a discharge of 8 ft^3/s, and a flat gradient. Otherwise, the physical characteristics of the study reaches were similar (fig. 12-13). Both were almost entirely riffle habitat, except for a short run in Camp Creek at transect 9 and a small pool downstream of transect 4. The substrate was dominated by small cobble and large gravel, with boulders distributed throughout Costello Creek. The surrounding tundra is typically devoid of trees and an open canopy characterizes both reaches, with sparse vegetation on the banks. Costello Creek had 6 percent riparian closure along the banks. Camp Creek had 21 percent riparian closure, primarily due to scattered willows along the banks between transects 8 and 11. Instream structure was predominantly formed by the distribution of cobbles and boulders, as woody debris was nearly absent.

Invertebrates

Benthic macroinvertebrate richest targeted habitat (RTH) and qualitative multi-habitat (QMH) samples were collected from Costello Creek above Camp Creek in 1998 and from Costello Creek below Camp Creek in 1999 (appendix 1). Eighteen taxa and 27 taxa were identified in the RTH samples, respectively. Greater than one-half of the individuals belonged to the order Diptera in both years. The 1998 sample consisted of 51 percent Chironomidae, dominated by two genera (*Diamesa, Cricotopus/Orthocladius*), with one abundant Ephemeroptera taxon, *Baetis bicaudatus*. The 1999 sample consisted of 72 percent Chironomidae, dominated by two genera (*Eukiefferiella, Cricotopus/Orthocladius*), with no particularly abundant taxa in Ephemeroptera, Plecoptera, or Tricoptera. The QMH sample identified an additional 9 taxa in 1998 and an additional 10 taxa in 1999.

Benthic macroinvertebrate RTH and QMH samples were also collected from Camp Creek during 1999 (appendix 1). Twenty-eight taxa were identified in the RTH sample, with one-half of the individuals belonging to the order Diptera. The family Chironomidae, dominated by *Eukiefferiella*, accounted for 48 percent of all individuals. One Tri-

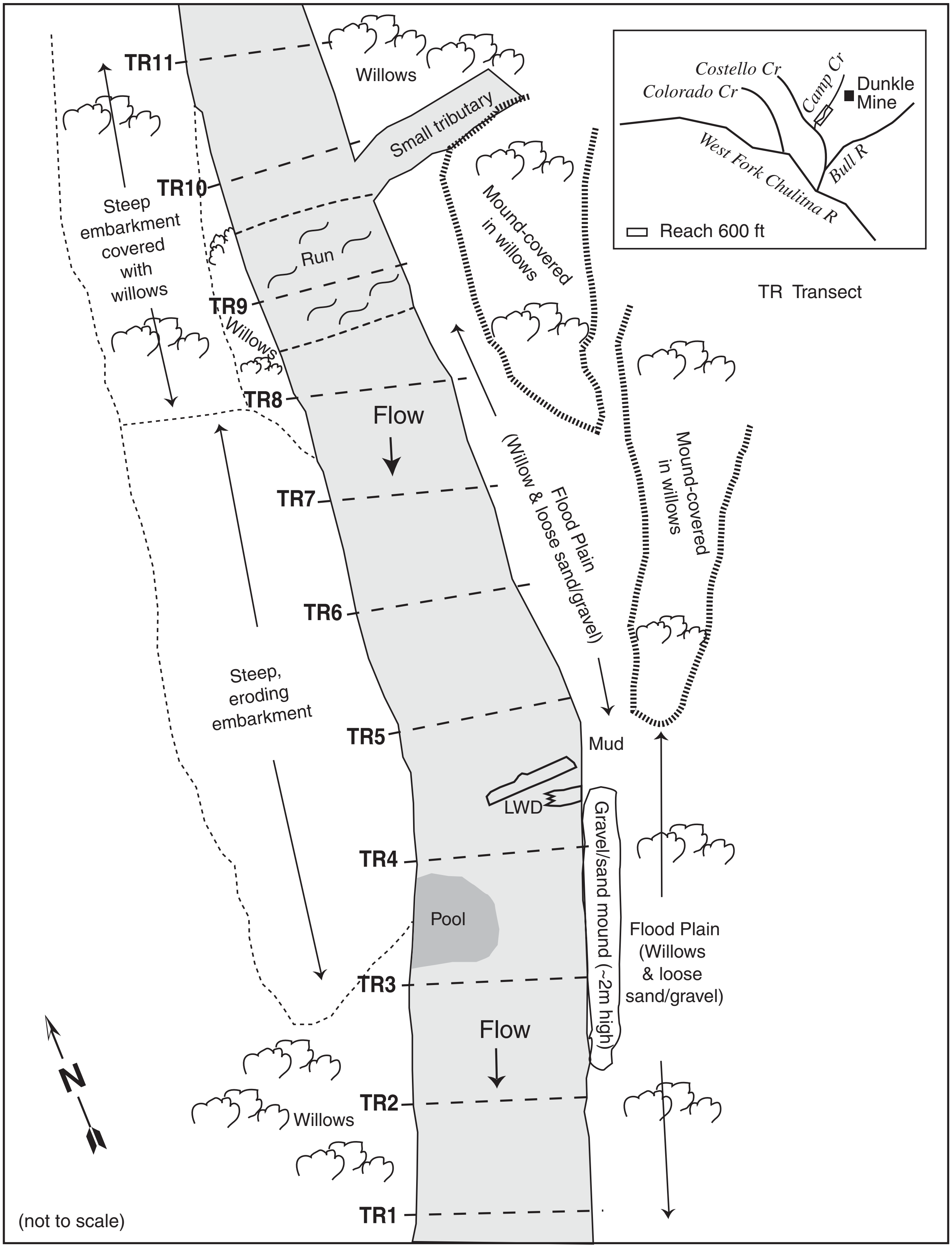

Figure 12. Major geomorphic features of the Camp Creek study reach.

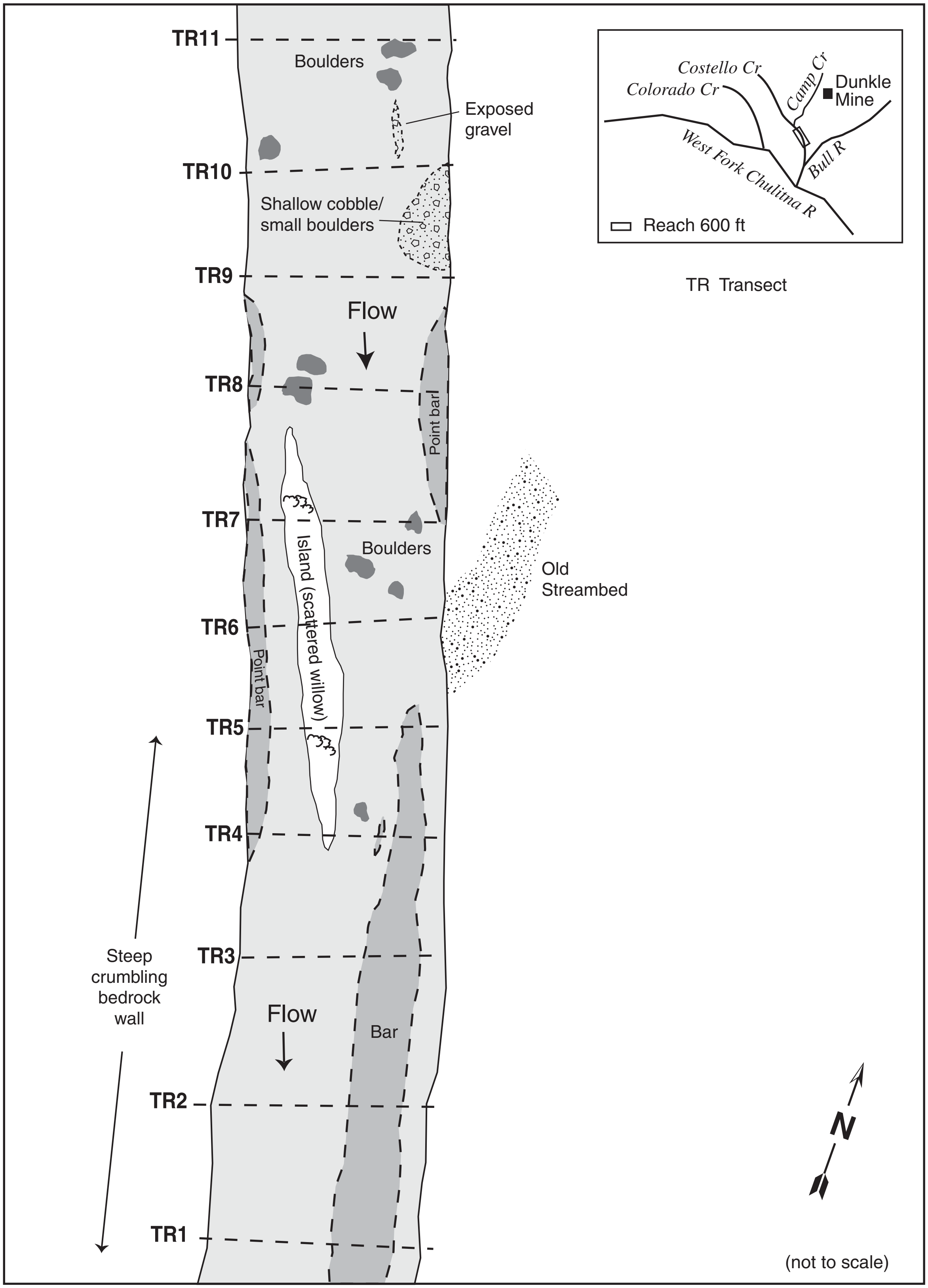

Figure 13. Major geomorphic features of the Costello Creek below Camp Creek study reach.

coptera genus, *Glossosoma*, was also abundant. The QMH sample identified an additional six taxa. Thus, all three sites represent typical interior Alaska taxonomic compositions (Oswood, 1989), with Diptera as the most abundant family, followed by Plecoptera and Ephemeroptera, and a relatively low proportion of Trichoptera.

Data were further examined at the community level by calculation of nine metrics that are sensitive to land-use disturbances (Cuffney, 2002) (table 24). These metrics shift in a predictable direction with increasing anthropogenic impacts (Gibson, 1996). The tolerance values of the organisms used with these metrics were obtained from the USEPA (Barbour and others, 1999). Once the metrics were calculated, the values were compared with a national data set (fig. 14).

Comparison of the metrics calculated for Camp Creek and Costello Creek to national values should be done with caution. The national data set is based on data from streams located in the contiguous United States. Because Camp Creek and Costello Creek are located at relatively high latitudes, Irons and others (1999) have noted that there are probably natural stressors such as frozen sediments and extreme temperature ranges that contribute to differences between these sites and streams in the contiguous United States. A data base for Alaska streams currently does not exist; however, it was felt that comparing data from Camp Creek and Costello Creek with the existing national data set would still provide some information.

Based on the comparison with the national data set, all metrics for all sites fall within the range of observations for mixed land use (fig. 14). Most of the metric values are similar to values from streams with at least some anthropogenic effects. Thus, based on this comparison, there might be some impact, although minimal, from the Dunkle Mine. However, it is more likely due to the fact that Camp Creek and Costello Creek are located at relatively high latitudes.

Camp Creek and Costello Creek below Camp Creek were sampled on consecutive days in 1999 and can be compared. All nine metrics indicate that Camp Creek has a macroinvertebrate assemblage more sensitive to poor water quality than Costello Creek (fig. 14). Additionally, water mites (Acari) were most abundant at Camp Creek, a taxon determined to be the most sensitive organism to sedimentation in interior Alaska (Wagener and LaPerriere, 1985); in many mined streams they are typically rare. Based on these data it is unlikely that past mining activities account for the variation in macroinvertebrate communities observed at these sites.

Algae

Periphytic algae RTH and QMH samples were collected from Costello Creek above Camp Creek in 1998 (appendix 2). Eleven taxa were identified in the RTH sample. A blue-green algae, *Amphithrix janthina*, was the most abundant taxon. The diatom community was dominated by *Encyonema silesiacum* and *Gomphonema angustatum*, which accounted for 40 percent of the diatoms sampled (fig. 15). The QMH sample identified 21 additional differentiated algae taxa.

Periphytic algae RTH, depositional targeted habitat (DTH), and QMH samples were collected from Costello Creek below Camp Creek in 1999 (appendix 2). Twenty-three and 22 taxa were identified in the RTH and DTH samples, respectively. *Amphithrix janthina* was the most abundant taxon in the RTH sample again, whereas *Hannaea arcus*, a diatom, was the most abundant taxon in the DTH sample. Four species accounted for 85 percent of all diatoms in the RTH sample and three species accounted for 58 percent of the diatoms in the DTH sample which also contained no soft algae (fig. 15). Eleven additional differentiated algae taxa were identified in the QMH sample.

Periphytic algae RTH, DTH, and QMH samples were also collected from Camp Creek in 1999 (appendix 2). Twenty-nine and 38 taxa were identified in the RTH and DTH samples, respectively. *Audouinella violecea*, a red algae, was the most abundant taxon in the RTH sample and *Amphithrix janthina* was the most abundant taxon in the DTH sample. One-half of the diatoms in the RTH sample were individuals from three species while four species accounted for 65 percent of the diatoms in the DTH sample (fig. 15). The QMH sample identified 15 additional differentiated algae taxa.

Four metrics responsive to anthropogenic disturbances were calculated for Camp Creek and Costello Creek below Camp Creek (Barbour and others, 1999; Stephen D. Porter, USGS, written communication, 2002) (table 25) since both RTH and DTH samples were collected during that year. Genus richness is typically highest at pristine sites or slightly disturbed sites and is often reduced at more affected sites. Similarly, diversity of algae may be maximized with minor perturbations and only decrease when greater effects occur. Because of the complex response patterns of these metrics they are most useful for relative comparisons in larger data sets, although values do provide useful baseline measures. Total algal biovolume approximates biomass and is an indicator of algal standing crop, estimating the volume of algal cells per surface area of substrate. The percent of diatoms that are motile is an indicator of siltation because diatoms that can move will survive sediment deposition better than sessile species that can be smothered. This is currently being utilized to rate the algal status of streams relative to national observations (Groschen and others, 2000; Potapova and others, 2002).

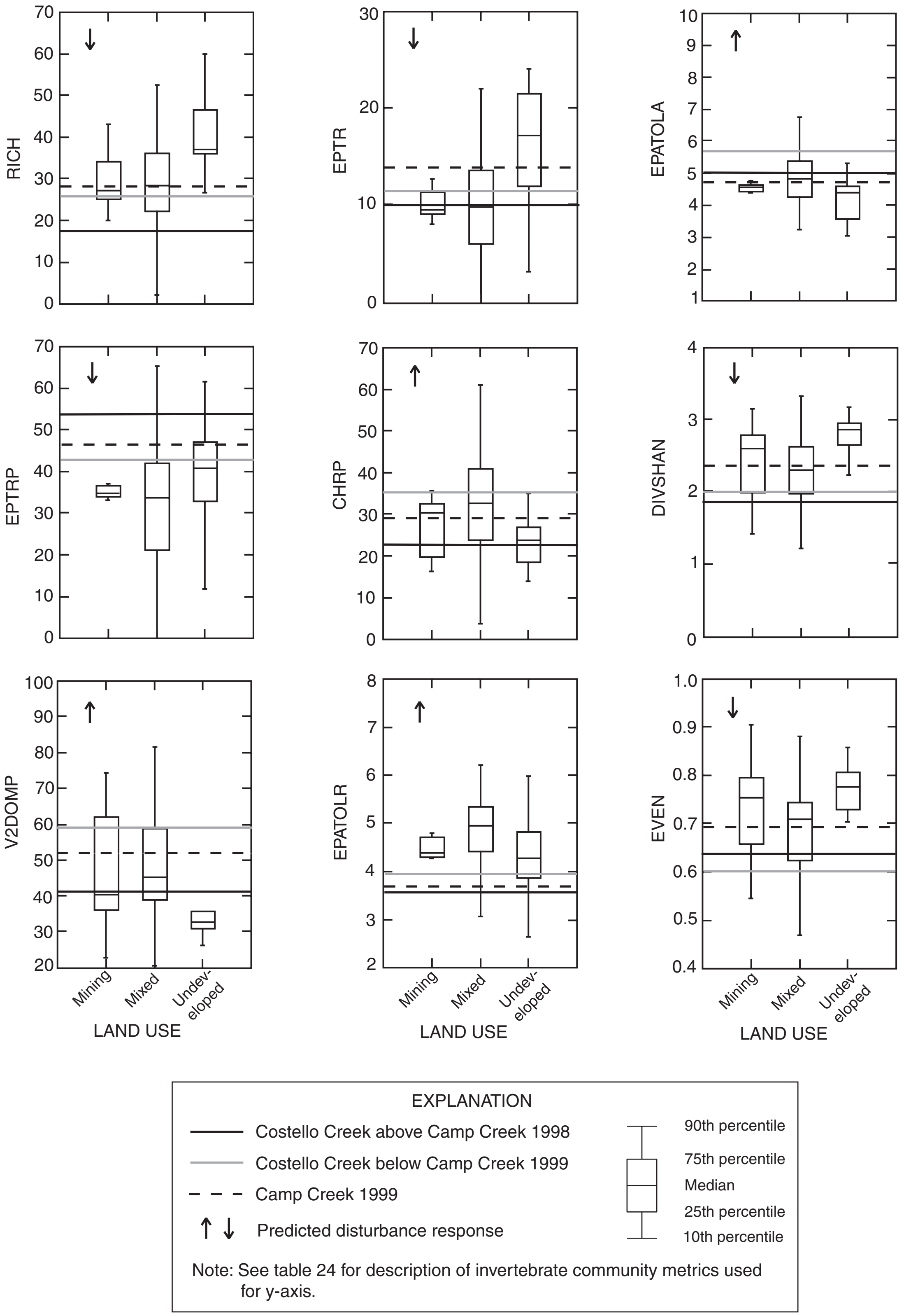

Figure 14. Invertebrate community metrics from Camp Creek and Costello Creek compared to national land-use values (Cuffney, 2002). (Classification for mixed land-use includes combinations of undeveloped, mining, agriculture, and urban uses.)

Table 24. Invertebrate community metrics (Cuffney, 2002)

Metric	Description
RICH	Total richness (number of taxa)
EPTR	Number of Ephemeroptera, Plecopters, and Tricoptera taxa
EPTRP	Percentage of taxa composed of Ephemeroptera, Plecoptera, and Tricoptera
CHRP	Percentage of taxa composed of Chironomidae larvae
V2DOMP	Percentage of total abundance represented by the two most abundant taxon
EPATOLR	Average EPA tolerance based on richness
EPATOLA	Average of abundance-weighted EPA tolerance
DIVSHAN	Shannon-Wiener diversity index
EVEN	Eveness (Shannon-Wiener diversity/maximum diversity)

Genus richness was very similar for RTH samples, but was more than twice as large in the Camp Creek DTH sample compared to Costello Creek below Camp Creek. Conversely, diversity was very similar for DTH samples, but was greater than 40 percent in Camp Creek for the RTH samples. Estimates of standing crop were also larger for both sample types from Camp Creek. In the DTH samples this was largely attributed to the presence of soft algae not found in the sample from Costello Creek. Calculation of a supplemental metric, percent similarity, further reflected differences in the algal communities at the two sites. RTH samples were only 29 percent similar and DTH samples were 37 percent similar. All samples for both sites had less than 10 percent motile diatoms, placing these sites in the top 25 percent nationally for least disturbed streams based on the algal status index (fig. 16).

Periphytic algae RTH and QMH samples were collected from Colorado Creek in 1998 (appendix 2). There were eight taxa found in the RTH sample, which was dominated by a blue-green algae, *Amphithrix janthina*. Greater than 50 percent of the diatoms were from the genus *Gomphonema* (fig. 15). Twenty-four other differentiated algae taxa were identified in the QMH sample.

The genus richness and biovolume in this sample were relatively low, similar to the 1998 sample from Costello Creek above Camp Creek, and dissimilar to the 1999 samples from Camp Creek and Costello Creek below Camp Creek. Like all the other sites, Colorado Creek ranks in the top 25 percent of streams nationally for low disturbance based on the algal status index.

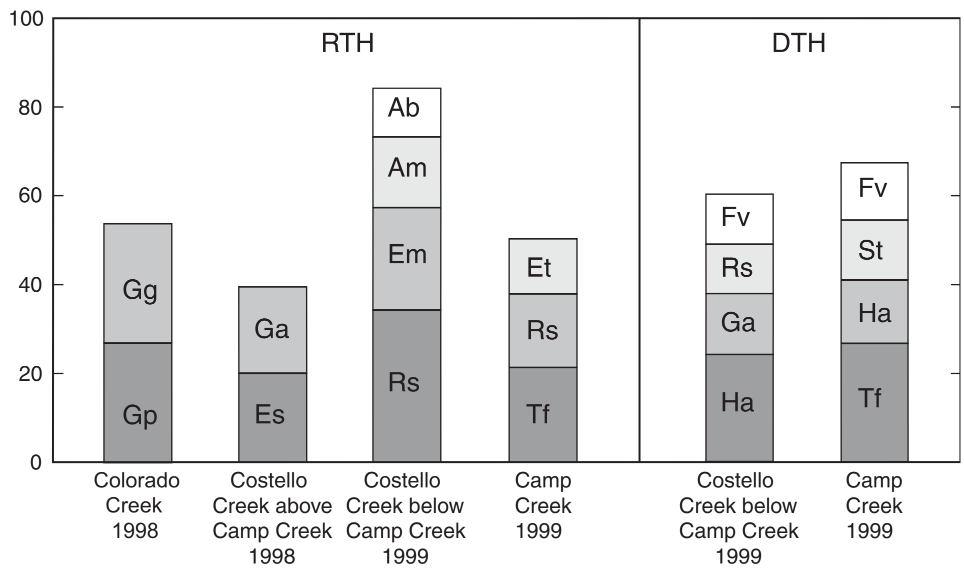

Figure 15. Relative abundance of diatoms at sampling sites for each species making up more than 10 percent of a sample (excludes soft algae). (Notations in appendix 2.)

Table 25. Metric values for algae samples

[cm^3/m^2; cubic centimeter per square meter; RTH, richest targeted habitat; DTH, depositional targeted habitat]

Site and sample type	Genus richness	Shannon-Wiener diversity (of diatoms)	Total algal biovolume (cm^3/m^2)	Percent motile diatoms (siltation index)
Camp Creek at mouth near Colorado -1999 RTH	21	2.60	5.27	5.9
Costello Creek below Camp Creek near Colorado - 1999 RTH	20	1.84	2.07	5.6
Camp Creek - 1999 DTH	31	2.62	31.19	6.1
Costello Creek below Camp Creek - 1999 DTH	14	2.57	7.80	9.2

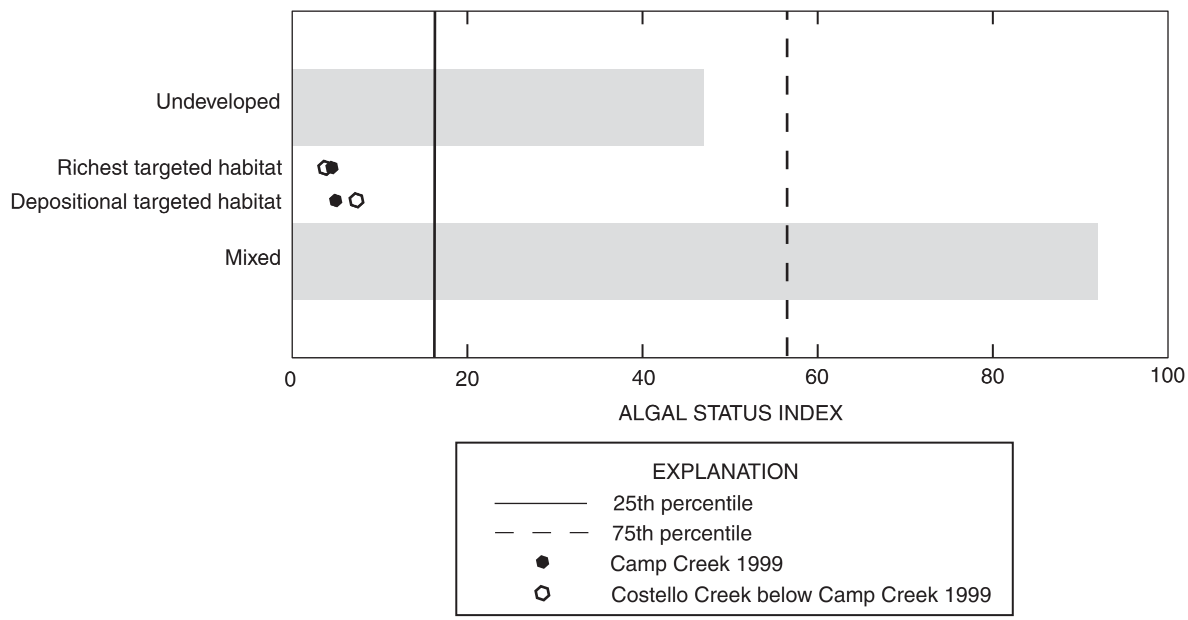

Figure 16. Algal status index for Camp Creek and Costello Creek below Camp Creek [RTH and DTH samples compared to the distribution of national values for different land-use types (Groschen and others, 2000). (Classification for mixed land-use includes combinations of undeveloped, mining, agriculture, and urban uses.)]

SUMMARY AND CONCLUSIONS

Camp Creek and its receiving stream, Costello Creek, are two small watersheds on the south side of Denali National Park and Preserve. Due to the concern about possible effects on water quality from the Dunkle Mine, which is located in the Camp Creek watershed, these two watersheds were studied during the summer runoff (June through September) from 1999 through 2000 as part of a cooperative study with the National Park Service. In addition to Camp Creek and Costello Creek, water-quality data from 23 other streams on the south side of Denali National Park and Preserve, were analyzed for similarities and differences in water quality compared to Camp Creek and Costello Creek. Streambed sediments from 13 of these sites were collected and analyzed for trace elements to supplement this analysis.

Analysis of water column, bed sediment, and fish data indicate no effects on the water quality of Camp Creek from the Dunkle Mine. Although several organic compounds were detected in the streambed of Camp Creek, all concentrations were below recommended levels for aquatic life and most of the concentrations were below the minimum reporting level of 50 *u*g/kg. Trace elements concentrations of arsenic, chromium, and nickel in the bed sediments of Camp Creek exceeded threshold effect concentrations (TEC), but concentrations of these trace elements were also exceeded in streambed sediments of Costello Creek above Camp Creek. Since the percent organic carbon in Camp Creek is relatively high, the toxicity quotient of 0.55 is only slightly above the threshold value of 0.5. Costello Creek has a relatively low organic carbon content and has a higher toxicity quotient of 1.19.

Analysis of the water-quality data for other streams located in the south side of Denali National Park and Preserve indicate similarities to Camp Creek and Costello Creek in terms of streamflow, water temperature, pH, specific conductance, and dissolved oxygen. Most of the streams are calcium bicarbonate type water with the exception of two streams that are calcium sulfate and magnesium sulfate type water. Trace element concentrations of arsenic, chromium, and nickel in the bed sediments of 9 streams exceeded the TEC or the probable effect concentration (PEC). Seven streams exceeded the threshold value of the toxicity quotient.

At sites where bed sediment was collected and analyzed for trace elements, a statistical technique, cluster analysis, indicated two distinct groups: basins that have some percentage of Tertiary deposits with low concentrations of arsenic, organic carbon, chromium, and copper, and basins that have a low percentage of Tertiary rocks and high concentrations of trace elements and organic carbon. As a check on the cluster analysis, another statistical techniques, a forward stepwise discriminant analysis, was done using the basin characteristics drainage area, amount of glaciers, and amount of tertiary deposits, cretaceous deposits, and quaternary deposits. This analysis divided the basins into the same groups as the cluster analysis. Thus, given the basin characteristics of a watershed, the discriminant function can be used to assign a probability of its trace element characteristics.

Analysis of invertebrate data from Camp Creek and Costello Creek indicate that these streams represent typical interior Alaska taxonomic compositions, with Diptera as the most abundant family, followed by Plecoptera and Ephemeroptera, and a relatively low proportion of Trichoptera. Metric analysis of the data indicate that Camp Creek has a macroinvertebrate assembledge more sensitive to poor water quality than Costello Creek. Thus, it is unlikely that past mining activities account for the variation in macroinvertebrate communities observed at Camp Creek and Costello Creek.

Based on an algal status index, Camp Creek, Costello Creek, and Colorado Creek rank in the top 25 percent of streams nationally for low disturbance. Genus richness and standing crop from depositional targeted habitat (DTH) samples from Camp Creek were more than twice as large as DTH samples from Costello Creek.

REFERENCES CITED

Aiken, G.R., and Cotsaris, E., 1995, Soil and hydrology—their effect on NOM: American Water Works Association, January, p. 36-45.

Arbogast, B.F., ed., 1990, Quality assurance manual for the Branch of Geochemistry, U.S. Geological Survey: U.S. Geological Survey Open-File Report 90-668, 184 p.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B., 1999, Rapid bioassessment protocols for use in streams and wadeable rivers—Periphyton, benthic macroinvertebrates, and fish (2d ed.): U.S. Environmental Protection Agency, Office of Water, Washington, D.C., EPA 841-B-99-002, accessed February 2002 at URL http://www.epa.gov/owowwtr1/monitoring/rbp/index.html

Canadian Council of Ministers of the Environment, 1995, Interim sediment quality guidelines: Soil and Sediment Quality Section Guidelines Division, Evaluation and Interpretation Branch Ecosystem Conservation Directorate, 65 p.

Canadian Council of Minister for the Environment, 1999, Canadian sediment quality guidelines for the protection of aquatic life-Summary tables, *in* Canadian Environmental Quality Guidelines, 1999: Winnipeg, Canadian Council of Ministers of the Environment.

Crawford, J.K., and Luoma, S.N., 1993, Guidelines for studies of contaminants in biological tissues for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 92-494, 69 p.

Cuffney, T.F., 2002, Invertebrate status index: accessed February 2002 at URL http://water.usgs.gov/nawqa/sumr/bioind/invertebrates.pdf

Cuffney, T.F., Gurtz, M.E., and Meador, M.R., 1993, Methods for collecting benthic invertebrate samples as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-406, 66 p.

Dale, B., and Stottlemyer, R., 1985, Heavy metal concentrations in soils, sediments, and surface water of mineral licks, Dunkle Mine, Denali National Park and Preserve, Alaska: GLARSU Report 10, National Park Service, Alaska Regional Office, 14 p.

Davis, J.C., 1986, Statistics and data analysis in geology: New York, John Wiley, 646 p.

Deacon, J.R., and Stephens, V.C., 1998, Trace elements in streambed sediment and fish liver at selected sites in the Upper Colorado River Basin, Colorado, 1995-96: U.S. Geological Survey Water-Resources Investigations Report 98-4124, 19 p.

Drever, J.I., 1997, The geochemistry of natural waters-surface and groundwater environments: Upper Saddle River, Prentice Hall, NJ, 438 p.

Edwards, P.J., and Tranel, M.J., 1998, Physical and chemical characterization of streams and rivers within Denali National Park and Preserve: Final Report submitted to National Park Service and U.S. Department of Agriculture Forest Service, 76 p.

Edwards, T.K., and Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86-531, 118 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.

Fishman, M.J., and Friedman, L.C., eds, 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resource Investigations, book 5, chap. A1, 545 p.

Fitzpatrick, F.A., Waite, I.R., D'Arconte, P.J., Meador, M.R., Maupin, M.A., and Gurtz, M.E., 1998, Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program: U.S. Geological Survey Water-Resource Investigations Report 98-4052, 67 p.

Frenzel, S.A., 2000, Selected organic compounds and trace elements in streambed sediments and fish tissues, Cook Inlet Basin, Alaska: U.S. Geological Survey Water-Resources Investigations Report 00-4004, 39 p.

Frenzel, S.A., and Dorava, J.M., 1999, Water-quality data for the Talkeetna River and four streams in National Parks, Cook Inlet Basin, Alaska, 1998: U.S. Geological Survey Open-File Report 99-459, 58 p.

Furlong, E.T., Vaught, D.G., Merten, L.M., Foreman, W.T., and Gates, P.M., 1996, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of semivolatile organic compounds in bottom sediment by solvent extraction, gel permeation chromatography/mass spectrometry: U.S. Geological Survey Open-File Report 95-719, 67 p.

Gibson, G.R., ed., 1996, Biological criteria—Technical guidance for streams and small rivers, revised edition: U.S. Environmental Protection Agency, Office of Science and Technology, Washington, D.C., EPA-822-B-96-001, 162 p.

Gilliom, R.J., Mueller, D.K., and Nowell, L.H., 1998, Methods for comparing water-quality conditions among National Water-Quality Assessment Study Units, 1992-1995: U.S. Geological Survey Open-File Report 97-589, 54 p.

Groschen, G.E., Harris, M.A., King, R.B., Terrio, P.J., and Warner, K.L., 2000, Water quality in the Lower Illinois River Basin, Illinois, 1995-98: U.S. Geological Survey Circular 1209, 37 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hoffman, G.L., 1996, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory-Preparation procedure for aquatic biological material determined for trace metals: U.S. Geological Survey Open-File Report 96-362, 42 p.

Irons, J.G., Ray, S.R., Miller, L.K., and Oswood, M.W., 1989, Spatial and seasonal patterns of streambed water temperatures in an Alaskan subarctic stream: Proceedings of the Symposium on Headwaters Hydrology, American Water Resources Association, Bethesda, Maryland, p. 381-390.

MacDonald, D.D., Ingersoll, C.G., and Berger, T.A., 2000, Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems: Archives of Environmental Contamination and Toxicology, v. 39, p. 20-31.

Magurran, A.E., 1988, Ecological diversity and its measurement: Princeton, New Jersey, Princeton University Press, 179 p.

Martin, J.M., and Whitfield, K., 1983, The significance of the river input of chemical elements to the ocean: *in* Wong, C.S., Boyle, E., Bruland, K.W., Burton, J.D., and Goldberg, E.D., (eds.), Trace Metals in Sea Water: New York, Plenum Press, p. 127-138

Meador, M.R., Cuffney, T.F., and Gurtz, M.E., 1993, Methods for fish communities as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-104, 40 p.

Merck Index, 1983, An encyclopedia of chemicals, drugs, and biologicals, (12th ed.): Rahway, NJ, Merck & Co., variuously paged.

Meybeck, M., 1988, How to establish and use world budgets of riverine materials: *in* Lerman, A., and Meybeck, M., (eds.), Physical and Chemical Weathering in Geochemical Cycles; Dordrecht, Kluwer Academic Publishers, p. 247-272.

National Park Service, 1983, Denali National Park and Preserve, Kantishna Hills/Dunkle Mine, Alaska, Draft environmental impact statement, 215 p.

Oswood, M.W., 1989, Community structure of benthic invertebrates in interior Alaskan (USA) streams and rivers: Hydrobiologia, v. 172, p. 97-110.

Parker, S.P., 1984, McGraw-Hill dictionary of chemical terms: New York, NY, McGraw-Hill Book Company, 470 p.

Patton, C.J., and Truitt, E.P., 1992, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of total phosphorus by a Kjeldahl digestion method and an automated colorimetric finish that includes dialysis: U.S. Geological Survey Open-File Report 92-146, 39 p.

Porter, S.D., Cuffney, T.F., Gurtz, M.E., and Meador, M.R., 1993, Methods for collecting algal samples as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File report 93-409, 39 p.

Potapova, M., Charles, D., and Porter, S.D., 2002, Algal status index: accessed February 2002 at URL http://water.usgs.gov/nawqa/sumr/bioind/invertebrates.pdf

Rantz, S.E., and others, 1982, Measurement and computation of streamflow, Volume 1. Measurement of discharge: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Rutledge, F.A., 1948, Investigation of the W.E. Dunkle coal mine, Costello Creek, Chulitna District, Alaska: Bureau of Mines Report of Investigations, October 1948, 9 p.

Sawyer, C.N., 1947, Fertilization of lakes by agricultural-urban drainage; Journal of New England Water Works Association, v. 61, p. 109-127.

Shelton, L.R., 1994, Field guide for collecting and processing stream water samples for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-455, 42 p.

Shelton, L.R., and Capel, P.D., 1994, Guidelines for collecting and processing samples of streambed sediment for analysis of trace elements and organic contaminants for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-458, 20 p.

Smith, K.S., and Huyck, L.O., 1999, An overview of the abundance, relative mobility, bioavailability, and human toxicity of metals: Reviews in Economic Geology, 6a, p. 29-70.

U.S. Department of the Interior, 1998, Guidelines for interpretation of the biological effects of selected constituents in biota, water, and sediment: National Irrigation Water Quality Program Information Report No. 3, 198 p.

U.S. Environmental Protection Agency, 1976, Quality criteria for water: U.S. Environmental Protection Agency, Washington, D. C., 256 p.

U.S. Environmental Protection Agency, 1996, Integrated Risk Information System (IRUS) [CD-ROM]: Enterprise, Florida, Solutions Software Corporation.

Van Derveer, W.D., and Canton, S., 1997, Selenium sediment toxicity thresholds and derivation of water quality criteria for freshwater biota of western stream: Environmental Toxicology and Chemistry, v. 16, p. 1260-1268.

Wagener, S.M., and LaPerriere, J.D., 1985, Effects of placer mining on the invertebrate communities of interior Alaska streams: Freshwater Invertebrate Biology, v. 4, no. 4, p. 208-214.

Wilson, F.H., Dover, J.H., Bradley, D.C., Weber, F.R., Bundtzen, T.K., and Haeussler, P.J., 1998, Geologic map of central (interior) Alaska: U.S. Geological Survey Open-File Report 98-133, 63 p., 3 plates.

APPENDIX

Appendix 1. Benthic macroinvertebrate data

[Abundance data for RTH samples is number of organisms per square meter; abundance data for QMH samples indicates the presence of that organism; Life stage: A, adult, L, larvae, P, pupae]

Class	Order	Family	Genus	Lowest taxonomic level	Life stage	Abundance
Costello Creek near Colorado (site number 58), Richest Target Habitat (RTH) sample August 12, 1998						
Arachnida				*Acari*		18
Insecta	Ephemeroptera	Caenidae	Caenis	*Caenis sp.*	L	3
Insecta	Ephemeroptera	Ephemerellidae	Drunella	*Drunella doddsi (Needham)*	L	7
Insecta	Ephemeroptera	Leptohyphidae	Tricorythodes	*Tricorythodes sp.*	L	3
Insecta	Ephemeroptera	Baetidae		*Baetidae*	A	18
Insecta	Ephemeroptera	Baetidae	Acentrella	*Acentrella sp.*	L	3
Insecta	Ephemeroptera	Baetidae	Acentrella	*Acentrella insignificans (McDunnough)*	L	15
Insecta	Ephemeroptera	Baetidae	Baetis	*Baetis sp.*	L	33
Insecta	Ephemeroptera	Baetidae	Baetis	*Baetis bicaudatus Dodds*	L	285
Insecta	Ephemeroptera	Heptageniidae	Cinygmula	*Cinygmula sp.*	L	21
Insecta	Ephemeroptera	Heptageniidae	Epeorus	*Epeorus sp.*	L	72
Insecta	Plecoptera	Taeniopterygidae		*Taeniopterygidae*	L	3
Insecta	Plecoptera	Chloroperlidae		*Chloroperlidae*	L	27
Insecta	Plecoptera	Chloroperlidae	Suwallia	*Suwallia sp.*	L	9
Insecta	Trichoptera	Glossosomatidae	Glossosoma	*Glossosoma sp.*	L	3
Insecta	Diptera	Chironomidae		*Chironomidae*	P	21
Insecta	Diptera	Chironomidae		*Chironomidae*	A	39
Insecta	Diptera	Chironomidae	Diamesa	*Diamesa sp.*	L	396
Insecta	Diptera	Chironomidae		*Orthocladiinae*	L	3
Insecta	Diptera	Chironomidae		*Orthocladiinae*	P	39
Insecta	Diptera	Chironomidae		*Cricotopus/Orthocladius sp.*	L	129
Insecta	Diptera	Chironomidae	Cricotopus	*Cricotopus trifascia group*	L	3
Insecta	Diptera	Chironomidae	Eukiefferiella	*Eukiefferiella sp.*	L	12
Insecta	Diptera	Simuliidae		*Simuliidae*	L	72
Insecta	Diptera	Simuliidae	Prosimulium	*Prosimulium sp.*	L	9
Insecta	Diptera	Tipulidae	Tipula	*Tipula sp.*	L	1
Insecta	Diptera	Empididae	Oreogeton	*Oreogeton sp.*	L	3
Costello Creek near Colorado (site number 58), Qualitative Multi-Habitat (QMH) Sample - August 12, 1998						
Insecta	Ephemeroptera	Ephemerellidae	Drunella	*Drunella doddsi (Needham)*	L	1
Insecta	Ephemeroptera	Baetidae	Baetis	*Baetis bicaudatus Dodds*	L	1
Insecta	Ephemeroptera	Heptageniidae	Cinygmula	*Cinygmula sp.*	L	1
Insecta	Ephemeroptera	Heptageniidae	Epeorus	*Epeorus sp.*	L	1
Insecta	Plecoptera	Capniidae		*Capniidae*	L	1
Insecta	Plecoptera	Nemouridae	Zapada	*Zapada sp.*	L	1
Insecta	Plecoptera	Chloroperlidae		*Chloroperlidae*	L	1
Insecta	Plecoptera	Chloroperlidae	Suwallia	*Suwallia sp.*	L	1
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	*Rhyacophila sp.*	L	1
Insecta	Diptera	Chironomidae		*Chironomidae*	L	1
Insecta	Diptera	Chironomidae	Micropsectra	*Micropsectra sp.*	L	1
Insecta	Diptera	Chironomidae	Diamesa	*Diamesa sp.*	L	1
Insecta	Diptera	Chironomidae	Pagastia	*Pagastia sp.*	L	1
Insecta	Diptera	Chironomidae		*Cricotopus/Orthocladius sp.*	L	1
Insecta	Diptera	Chironomidae	Eukiefferiella	*Eukiefferiella sp.*	L	1
Insecta	Diptera	Chironomidae	Parorthocladius	*Parorthocladius sp.*	L	1
Insecta	Diptera	Chironomidae	Rheocricotopus	*Rheocricotopus sp.*	L	1
Insecta	Diptera	Chironomidae	Thienemanniella	*Thienemanniella sp.*	L	1
Insecta	Diptera	Psychodidae		*Pericoma/Telmatoscopus sp.*	L	1
Insecta	Diptera	Simuliidae		*Simuliidae*	L	1
Insecta	Diptera	Simuliidae	Prosimulium	*Prosimulium sp.*	L	1
Insecta	Diptera	Tipulidae	Tipula	*Tipula sp.*	L	1

Appendix 1. Benthic macroinvertebrate data

[Abundance data for RTH samples is number of organisms per square meter; abundance data for QMH samples indicates the presence of that organism; Life stage: A, adult, L, larvae, P, pupae]

Class	Order	Family	Genus	Lowest taxonomic level	Life stage	Abundance
Costello Creek below Camp Creek near Colorado (site number 96), Richest Targeted Habitat (RTH) Sample - August 3, 1999						
	Acari			*Hydrachnidia*		34
Insecta	Collembola			*Collembola*		5
Insecta	Ephemeroptera	Ephemerellidae		*Ephemerellidae*	L	2
Insecta	Ephemeroptera	Ephemerellidae	Drunella	*Drunella doddsi (Needham)*	L	5
Insecta	Ephemeroptera	Ameletidae	Ameletus	*Ameletus sp.*	L	2
Insecta	Ephemeroptera	Baetidae		*Baetidae*	L	2
Insecta	Ephemeroptera	Baetidae	Baetis	*Baetis bicaudatus Dodds*	L	19
Insecta	Ephemeroptera	Heptageniidae	Cinygmula	*Cinygmula sp.*	L	8
Insecta	Ephemeroptera	Heptageniidae	Epeorus	*Epeorus sp.*	L	43
Insecta	Plecoptera	Capniidae		*Capniidae*	L	2
Insecta	Plecoptera	Nemouridae	Zapada	*Zapada sp.*	L	10
Insecta	Plecoptera	Taeniopterygidae	Taenionema	*Taenionema sp.*	L	2
Insecta	Plecoptera	Chloroperlidae		*Chloroperlidae*	L	38
Insecta	Plecoptera	Chloroperlidae	Suwallia	*Suwallia sp.*	L	1
Insecta	Trichoptera	Glossosomatidae	Glossosoma	*Glossosoma sp.*	L	14
Insecta	Trichoptera	Limnephilidae		*Limnephilidae*	L	10
Insecta	Trichoptera	Limnephilidae		*Limnephilidae*	P	2
Insecta	Coleoptera	Staphylinidae		*Staphylinidae*	A	3
Insecta	Diptera	Ceratopogonidae		*Bezzia/Palpomyia sp.*	L	2
Insecta	Diptera	Ceratopogonidae	Forcipomyia	*Forcipomyia sp.*	L	2
Insecta	Diptera	Chironomidae		*Chironomidae*	A	10
Insecta	Diptera	Chironomidae		*Chironomidae*	L	2
Insecta	Diptera	Chironomidae		*Chironomidae*	P	17
Insecta	Diptera	Chironomidae	Tanytarsus	*Tanytarsus sp.*	L	2
Insecta	Diptera	Chironomidae		*Diamesinae*	L	7
Insecta	Diptera	Chironomidae	Diamesa	*Diamesa sp.*	L	38
Insecta	Diptera	Chironomidae	Pagastia	*Pagastia sp.*	L	5
Insecta	Diptera	Chironomidae	Syndiamesa	*Syndiamesa sp.*	L	17
Insecta	Diptera	Chironomidae		*Orthocladiinae*	L	36
Insecta	Diptera	Chironomidae		*Orthocladiinae*	P	5
Insecta	Diptera	Chironomidae		*Cricotopus/Orthocladius sp.*	L	182
Insecta	Diptera	Chironomidae	Chaetocladius	*Chaetocladius sp.*	L	5
Insecta	Diptera	Chironomidae	Eukiefferiella	*Eukiefferiella sp.*	L	192
Insecta	Diptera	Chironomidae	Parorthocladius	*Parorthocladius sp.*	L	24
Insecta	Diptera	Chironomidae	Rheocricotopus	Rheocricotopus sp.	L	2
Insecta	Diptera	Chironomidae	Parochlus	Parochlus kiefferi (Garrett)	L	2
Insecta	Diptera	Simuliidae		Simuliidae	L	10
Costello Creek below Camp Creek near Colorado (site number 96), Qualitative Multi-Habitat (QMH) Sample -August 3, 1999						
Turbellaria				*Turbellaria*		1
	Acari			*Hydrachnidia*		1
Insecta	Ephemeroptera	Ephemerellidae	Drunella	*Drunella doddsi (Needham)*	L	1
Insecta	Ephemeroptera	Ameletidae	Ameletus	*Ameletus sp.*	L	1
Insecta	Ephemeroptera	Baetidae	Baetis	*Baetis bicaudatus Dodds*	L	1
Insecta	Ephemeroptera	Heptageniidae	Cinygmula	*Cinygmula sp.*	L	1
Insecta	Ephemeroptera	Heptageniidae	Epeorus	*Epeorus sp.*	L	1
Insecta	Plecoptera	Capniidae		*Capniidae*	L	1
Insecta	Plecoptera	Nemouridae	Zapada	*Zapada sp.*	L	1
Insecta	Plecoptera	Chloroperlidae		*Chloroperlidae*	L	1
Insecta	Plecoptera	Perlodidae	Isoperla	*Isoperla sp.*	L	1
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	*Rhyacophila sp.*	L	1
Insecta	Trichoptera	Limnephilidae	Ecclisomyia	*Ecclisomyia sp.*	L	1
Insecta	Diptera	Chironomidae		*Chironomidae*	L	1
Insecta	Diptera	Chironomidae	Diamesa	*Diamesa sp.*	L	1
Insecta	Diptera	Chironomidae	Pagastia	*Pagastia sp.*	L	1
Insecta	Diptera	Chironomidae	Syndiamesa	*Syndiamesa sp.*	L	1
Insecta	Diptera	Chironomidae		*Orthocladiinae*	L	1

Appendix 1. Benthic macroinvertebrate data

[Abundance data for RTH samples is number of organisms per square meter; abundance data for QMH samples indicates the presence of that organism; Life stage: A, adult, L, larvae, P, pupae]

Class	Order	Family	Genus	Lowest taxonomic level	Life stage	Abundance
Costello Creek below Camp Creek near Colorado (site number 96), Qualitative Multi-Habitat (QMH) Sample -August 3, 1999—Continued						
Insecta	Diptera	Chironomidae		*Cricotopus/Orthocladius sp.*	L	1
Insecta	Diptera	Chironomidae	Diplocladius	*Diplocladius sp.*	L	1
Insecta	Diptera	Chironomidae	Eukiefferiella	*Eukiefferiella sp.*	L	1
Insecta	Diptera	Chironomidae	Heleniella	*Heleniella sp.*	L	1
Insecta	Diptera	Chironomidae	Pseudosmittia	*Pseudosmittia sp.*	L	1
Insecta	Diptera	Chironomidae	Rheocricotopus	*Rheocricotopus sp.*	L	1
Insecta	Diptera	Chironomidae	Synorthocladius	*Synorthocladius sp.*	L	1
Insecta	Diptera	Chironomidae	Tvetenia	*Tvetenia sp.*	L	1
Insecta	Diptera	Culicidae		*Culicidae*	A	1
Insecta	Diptera	Simuliidae		*Simuliidae*	L	1
Insecta	Diptera	Tipulidae	Tipula	*Tipula sp.*	L	1
Insecta	Diptera	Empididae	Oreogeton	*Oreogeton sp.*	L	1
Camp Creek at mouth near Colorado (site number 95), Richest Targeted Habitat (RTH) Sample - August 4, 1999						
Turbellaria				*Turbellaria*		2
	Acari			*Hydrachnidia*		68
Insecta	Collembola			*Collembola*		8
Insecta	Ephemeroptera	Ephemerellidae		*Ephemerellidae*	L	2
Insecta	Ephemeroptera	Ephemerellidae	Drunella	*Drunella doddsi (Needham)*	L	5
Insecta	Ephemeroptera	Ameletidae	Ameletus	*Ameletus sp.*	L	2
Insecta	Ephemeroptera	Baetidae		*Baetidae*	A	2
Insecta	Ephemeroptera	Baetidae	Acentrella	*Acentrella turbida (McDunnough)*	L	12
Insecta	Ephemeroptera	Baetidae	Baetis	*Baetis tricaudatus Dodds*	L	3
Insecta	Ephemeroptera	Heptageniidae		*Heptageniidae*	L	2
Insecta	Ephemeroptera	Heptageniidae	Cinygmula	*Cinygmula sp.*	L	8
Insecta	Ephemeroptera	Heptageniidae	Epeorus	*Epeorus sp.*	L	12
Insecta	Plecoptera	Capniidae		*Capniidae*	L	2
Insecta	Plecoptera	Leuctridae	Despaxia	*Despaxia augusta (Banks)*	L	3
Insecta	Plecoptera	Nemouridae	Zapada	*Zapada sp.*	L	6
Insecta	Plecoptera	Nemouridae	Zapada	*Zapada cinctipes (Banks)*	L	2
Insecta	Plecoptera	Chloroperlidae		*Chloroperlidae*	L	5
Insecta	Plecoptera	Perlodidae		*Perlodidae*	L	2
Insecta	Trichoptera	Glossosomatidae	Glossosoma	*Glossosoma sp.*	L	104
Insecta	Trichoptera	Limnephilidae		*Limnephilidae*	L	5
Insecta	Diptera	Ceratopogonidae		*Bezzia/Palpomyia sp.*	L	2
Insecta	Diptera	Chironomidae		*Chironomidae*	A	20
Insecta	Diptera	Chironomidae		*Chironomidae*	P	3
Insecta	Diptera	Chironomidae		*Chironominae*	P	2
Insecta	Diptera	Chironomidae		*Tanytarsini*	L	2
Insecta	Diptera	Chironomidae	Rheotanytarsus	*Rheotanytarsus sp.*	P	2
Insecta	Diptera	Chironomidae	Stempellina	*Stempellina sp.*	L	2
Insecta	Diptera	Chironomidae	Stempellinella	*Stempellinella sp.*	P	2
Insecta	Diptera	Chironomidae		*Orthocladiinae*	L	8
Insecta	Diptera	Chironomidae		*Orthocladiinae*	P	5
Insecta	Diptera	Chironomidae		*Cricotopus/Orthocladius sp.*	L	27
Insecta	Diptera	Chironomidae	Brillia	*Brillia sp.*	L	2
Insecta	Diptera	Chironomidae	Corynoneura	*Corynoneura sp.*	L	2
Insecta	Diptera	Chironomidae	Eukiefferiella	*Eukiefferiella sp.*	L	119
Insecta	Diptera	Chironomidae	Parorthocladius	*Parorthocladius sp.*	L	6
Insecta	Diptera	Chironomidae	Thienemanniella	*Thienemanniella sp.*	L	27
Insecta	Diptera	Chironomidae	Tvetenia	Tvetenia sp.	L	15
Insecta	Diptera	Chironomidae		Thienemannimyia group sp. (Coffman and Ferrington)	L	2
Insecta	Diptera	Simuliidae		Simuliidae	L	5
Insecta	Diptera	Simuliidae	Simulium	Simulium sp.	A	2
Insecta	Diptera	Simuliidae	Simulium	Simulium sp.	L	2

Appendix 1. Benthic macroinvertebrate data

[Abundance data for RTH samples is number of organisms per square meter; abundance data for QMH samples indicates the presence of that organism; Life stage: A, adult, L, larvae, P, pupae]

Class	Order	Family	Genus	Lowest taxonomic level	Life stage	Abundance
Camp Creek at mouth near Colorado (site number 95), Qualitative Multi-Habitat (QMH) Sample - 8-4-1999						
Gastropoda		Valvatidae	Valvata	*Valvata sp.*		1
Gastropoda		Hydrobiidae		*Hydrobiidae*		1
	Acari			*Hydrachnidia*		1
Insecta	Ephemeroptera	Ephemerellidae		*Ephemerellidae*	L	1
Insecta	Ephemeroptera	Ameletidae	Ameletus	*Ameletus sp.*	L	1
Insecta	Ephemeroptera	Baetidae	Acentrella	*Acentrella turbida (McDunnough)*	L	1
Insecta	Ephemeroptera	Baetidae	Baetis	*Baetis sp.*	L	1
Insecta	Ephemeroptera	Heptageniidae	Epeorus	*Epeorus sp.*	L	1
Insecta	Plecoptera	Leuctridae	Despaxia	*Despaxia augusta (Banks)*	L	1
Insecta	Plecoptera	Chloroperlidae		*Chloroperlidae*	L	1
Insecta	Plecoptera	Chloroperlidae	Suwallia	*Suwallia sp.*	L	1
Insecta	Trichoptera	Glossosomatidae	Glossosoma	*Glossosoma sp.*	L	1
Insecta	Trichoptera	Brachycentridae	Brachycentrus	*Brachycentrus americanus (Banks)*	L	1
Insecta	Diptera	Chironomidae	Pagastia	*Pagastia sp.*	L	1
Insecta	Diptera	Chironomidae		*Orthocladiinae*	L	1
Insecta	Diptera	Chironomidae		*Cricotopus/Orthocladius sp.*	L	1
Insecta	Diptera	Chironomidae	Corynoneura	*Corynoneura sp.*	L	1
Insecta	Diptera	Chironomidae	Eukiefferiella	*Eukiefferiella sp.*	L	1
Insecta	Diptera	Chironomidae	Parametriocnemus	*Parametriocnemus sp.*	L	1
Insecta	Diptera	Chironomidae	Parorthocladius	*Parorthocladius sp.*	L	1
Insecta	Diptera	Chironomidae	Thienemanniella	*Thienemanniella sp.*	L	1
Insecta	Diptera	Chironomidae	Tvetenia	*Tvetenia sp.*	L	1
Insecta	Diptera	Simuliidae		*Simuliidae*	L	1

Appendix 2. Periphytic algae data

[Abundance data for RTH and DTH samples is number of cells per square centimeter; biovolume data for RTH and DTH samples is cubic micrometers per square centimeter; abundance data for QMH samples indicates the presence of that organism]

Algae group	Phylum	Family	Genus	Lowest taxonomic level	Notation	Abundance	Biovolume
Colorado Creek near Colorado, (site number 57), Richest Targeted Habitat (RTH) Sample - August 13, 1998							
Diatoms	Chrysophyta	Achnanthaceae	Achnanthes	*Achnanthes pusilla (Grunow) DeToni*		176	11,000
Diatoms	Chrysophyta	Achnanthaceae	Achnanthes	*Achnanthes lanceolata (Brébisson in Kützing) Grunow*		176	49,700
Diatoms	Chrysophyta	Diatomaceae	Meridion	*Meridion circulare (Grev.) Ag.*		176	112,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema gracile Ehr. emend. V. H.*	Gg	527	429,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema parvulum (K¸tz.) K¸tz.*		176	38,200
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema parvulum var. parvulius Lange-Bertalot & Reichardt*	Gp	527	158,000
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia palea (Kütz.) W. Sm.*		176	53,400
Blue-Green	Cyanophyta	Nostocaceae	Amphithrix	*Amphithrix janthina (Mont.) Born. and Flah.*		36400	300,000
Colorado Creek near Colorado, (site number 57), Qualitative Multi-Habitat (QMH) Sample - August 13, 1998							
Diatoms	Chrysophyta	Achnanthaceae	Achnanthes	*Achnanthes exigua var. heterovalva Krasske*		1	
Diatoms	Chrysophyta	Achnanthaceae	Achnanthes	*Achnanthes lanceolata (Brébisson in Kützing) Grunow*		1	
Diatoms	Chrysophyta	Achnanthaceae	Achnanthes	*Achnanthes lanceolata subsp. rostrata (Øestrup) Lange-Bertalot*		1	
Diatoms	Chrysophyta	Achnanthaceae	Achnanthes	*Achnanthes pusilla (Grunow) DeToni*		1	
Diatoms	Chrysophyta	Achnanthaceae	Cocconeis	*Cocconeis placentula var. lineata (Ehrenberg) Van Heurck*		1	
Diatoms	Chrysophyta	Achnanthaceae	Psammothidium	*Psammothidium bioretii (Germ.) Bukht. et Round*		1	
Diatoms	Chrysophyta	Diatomaceae	Fragilaria	*Fragilaria capucina var. rumpens (Kützing) Lange-Bertalot*		1	
Diatoms	Chrysophyta	Diatomaceae	Hannaea	*Hannaea arcus (Ehr.) Patr.*		1	
Diatoms	Chrysophyta	Diatomaceae	Meridion	*Meridion circulare (Grev.) Ag.*		1	
Diatoms	Chrysophyta	Diatomaceae	Staurosira	*Staurosira construens var. venter (Ehr.) Hamilton*		1	
Diatoms	Chrysophyta	Naviculaceae	Caloneis	*Caloneis bacillum (Grunow) Cleve*		1	
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema minutum (Hilse) Mann*		1	
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema silesiacum (Bleisch) Mann*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema olivaceum (Lyngb.) Kütz.*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema gracile Ehr. emend. V. H.*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema minutum (Ag.) Ag.*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema parvulum var. parvulius Lange-Bertalot & Reichardt*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema sarcophagus Greg.*		1	
Diatoms	Chrysophyta	Naviculaceae	Neidium	*Neidium sp.1 ANS LJM*		1	
Diatoms	Chrysophyta	Naviculaceae	Pinnularia	*Pinnularia borealis Ehrenberg*		1	
Diatoms	Chrysophyta	Naviculaceae	Pinnularia	*Pinnularia microstauron (Ehr.) Cl.*		1	
Diatoms	Chrysophyta	Naviculaceae	Reimeria	*Reimeria sinuata (Greg.) Kociolek & Stoermer*		1	
Diatoms	Chrysophyta	Naviculaceae	Stauroneis	*Stauroneis phoenicenteron (Nitz.) Ehr.*		1	
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia linearis (Ag. ex W. Sm.) W. Sm.*		1	
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia dissipata (Kütz.) Grun.*		1	
Blue-Green	Cyanophyta	Nostocaceae	Anabaena	*Anabaena subcylindrica Borge*		1	
Blue-Green	Cyanophyta	Oscillatoriaceae	Oscillatoria	*Oscillatoria princeps Vauch.*		1	
Green	Chlorophyta	Chaetophoraceae	Stigeoclonium	*Stigeoclonium lubricum (Dillw.) Kütz.*		1	

Appendix 2. Periphytic algae data

[Abundance data for RTH and DTH samples is number of cells per square centimeter; biovolume data for RTH and DTH samples is cubic micrometers per square centimeter; abundance data for QMH samples indicates the presence of that organism]

Algae group	Phylum	Family	Genus	Lowest taxonomic level	Notation	Abundance	Biovolume
Costello Creek near Colorado, (site number 58), Richest Targeted Habitat (RTH) Sample - August 12, 1998							
Diatoms	Chrysophyta	Diatomaceae	Staurosirella	*Staurosirella pinnata (Her.) Williams & Round*		197	295,000
Diatoms	Chrysophyta	Naviculaceae	Cymbella	*Cymbella cymbiformis Ag.*		197	164,000
Diatoms	Chrysophyta	Naviculaceae	Didymosphenia	*Didymosphenia geminata (Lyngb.) M. Schmidt*		197	10,800,000
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema silesiacum (Bleic. in Raben.) Mann*	Es	394	250,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema subclavatum (Grun.) Grun.*		197	156,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema angustatum (Kütz.) Rabh.*	Ga	394	158,000
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula radiosa var. tenella (Bréb. ex Kütz.) Grun.*		197	40,000
Diatoms	Chrysophyta	Thalassiosiraceae	Cyclotella	*Cyclotella meneghiniana Kützing*		197	144,000
Blue-green	Cyanophyta	Nostocaceae	Amphithrix	*Amphithrix janthina (Mont.) Born. And Flah.*		10,100	126,000
Blue-green	Cyanophyta	Oscillatoriaceae	Oscillatoria	*Oscillatoria granulata Gardner*		5,710	207,000
Blue-green	Cyanophyta	Oscillatoriaceae	Oscillatoria	*Oscillatoria sp.*		1,980	246,000
Costello Creek near Colorado, (site number 58), Qualitative Multi-Habitat (QMH) Sample - August 12, 1998							
Diatoms	Chrysophyta	Achnanthaceae	Achnanthidium	*Achnanthidium minutissimum (Küzing) Czarnecki*		1	
Diatoms	Chrysophyta	Achnanthaceae	Planothidium	*Planothidium lanceolatum*		1	
Diatoms	Chrysophyta	Diatomaceae	Fragilaria	*Fragilaria vaucheriae (Kütz.) Peters.*		1	
Diatoms	Chrysophyta	Diatomaceae	Hannaea	*Hannaea arcus (Ehr.) Patr.*		1	
Diatoms	Chrysophyta	Diatomaceae	Meridion	*Meridion circulare (Grev.) Ag.*		1	
Diatoms	Chrysophyta	Diatomaceae	Staurosira	*Staurosira construens var. venter (Ehr.) Hamilton*		1	
Diatoms	Chrysophyta	Diatomaceae	Staurosirella	*Staurosirella leptostauron Ehr.*		1	
Diatoms	Chrysophyta	Diatomaceae	Synedra	*Synedra ulna (Nitz.) Ehr.*		1	
Diatoms	Chrysophyta	Eunotiaceae	Eunotia	*Eunotia pectinalis (O. F. Müll.) Rabh.*		1	
Diatoms	Chrysophyta	Naviculaceae	Cymbella	*Cymbella cistula (Ehr.) Kirchn.*		1	
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema minutum (Hilse in Rabenhorst) Mann*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema angustatum (K¸üz.) Rabh.*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema minutum (Ag.) Ag.*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema olivaceoides Hust.*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema parvulum (Kütz.) Kütz.*		1	
Diatoms	Chrysophyta	Naviculaceae	Luticola	*Luticola mutica (Kütz.) Mann*		1	
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula leptostriata Jorg.*		1	
Diatoms	Chrysophyta	Naviculaceae	Pinnularia	*Pinnularia subcapitata Greg.*		1	
Diatoms	Chrysophyta	Naviculaceae	Reimeria	*Reimeria sinuata (Greg.) Kociolek & Stoermer*		1	
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia palea (Kütz.) W. Sm.*		1	
Diatoms	Chrysophyta	unknown	undifferentiated	*undifferentiated diatoms*		1	
Diatoms	Chrysophyta	unknown	undifferentiated	*undifferentiated diatoms*		1	
Blue-green	Cyanophyta	Nostocaceae	Anabaena	*Anabaena sp.*		1	
Green	Chlorophyta	Zygnemataceae	Mougeotia	*Mougeotia sp.*		1	

Appendix 2. Periphytic algae data

[Abundance data for RTH and DTH samples is number of cells per square centimeter; biovolume data for RTH and DTH samples is cubic micrometers per square centimeter; abundance data for QMH samples indicates the presence of that organism]

Algae group	Phylum	Family	Genus	Lowest taxonomic level	Notation	Abundance	Biovolume
Costello Creek below Camp Creek near Colorado, (site number 96), Richest Targeted Habitat (RTH) Sample - August 3, 1999							
Diatoms	Chrysophyta	Achnanthaceae	Achnanthes	*Achnanthes biasolettiana (Kützing) Grunow*	Ab	1,480	183,000
Diatoms	Chrysophyta	Achnanthaceae	Achnanthidium	*Achnanthidium minutissimum (Kützing) Czarnecki*	Am	2,170	118,000
Diatoms	Chrysophyta	Achnanthaceae	Cocconeis	*Cocconeis placentula var. lineata (Ehrenberg) Van Heurck*		29	28,700
Diatoms	Chrysophyta	Achnanthaceae	Planothidium	*Planothidium lanceolatum*		29	5,490
Diatoms	Chrysophyta	Diatomaceae	Fragilaria	*Fragilaria vaucheriae (Kütz.) Peters.*		114	22,600
Diatoms	Chrysophyta	Diatomaceae	Meridion	*Meridion circulare (Grev.) Ag.*		57	36,200
Diatoms	Chrysophyta	Diatomaceae	Staurosirella	*Staurosirella pinnata (Her.) Williams & Round*		57	85,400
Diatoms	Chrysophyta	Naviculaceae	Amphora	*Amphora pediculus (Kützing) Grun.*		399	42,000
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema minutum (Hilse in Rabenhorst) Mann*	Em	3,140	575,000
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema silesiacum (Bleic. in Raben.) Mann*		114	72,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema parvulum (Kütz.) Kütz.*		29	6,160
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema angustatum (K¸tz.) Rabh.*		228	91,800
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema gracile Ehr. emend. V. H.*		29	23,200
Diatoms	Chrysophyta	Naviculaceae	Luticola	*Luticola goeppertiana Mann*		57	428,000
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula minima Grun.*		570	27,000
Diatoms	Chrysophyta	Naviculaceae	Reimeria	*Reimeria sinuata (Greg.) Kociolek & Stoermer*	Rs	4,590	754,000
Diatoms	Chrysophyta	Naviculaceae	Sellaphora	*Sellaphora seminulum (Grun.) Mann*		57	3,090
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia inconspicua Grun.*		171	6,120
Blue-green	Cyanophyta	Nostocaceae	Amphithrix	*Amphithrix janthina (Mont.) Born. And Flah.*		39,000	490,000
Blue-green	Cyanophyta	Oscillatoriaceae	Microcoleus	*Microcoleus vaginatus (Vauch.) Gom.*		10,800	357,000
Blue-green	Cyanophyta	Oscillatoriaceae	Oscillatoria	*Oscillatoria sp.*		3,950	491,000
Green	Chlorophyta	Chaetophoraceae	Stigeoclonium	*Stigeoclonium lubricum (Dillw.) Kütz.*		8,380	11,000,000
Red	Rhodophyta	Chantransiacea	Audouinella	*Audouinella violacea Kütz.*		31,800	193,000,000
Costello Creek below Camp Creek near Colorado (site number 96), Depositional Targeted Habitat (DTH) Sample - August 3, 1999							
Diatoms	Chrysophyta	Achnanthaceae	Planothidium	*Planothidium lanceolatum*		18,300	3,520,000
Diatoms	Chrysophyta	Diatomaceae	Diatoma	*Diatoma mesodon (Ehr.) Kütz.*		27,400	23,300,000
Diatoms	Chrysophyta	Diatomaceae	Fragilaria	*Fragilaria vaucheriae (Kütz.) Peters.*	Fv	119,000	23,500,000
Diatoms	Chrysophyta	Diatomaceae	Hannaea	*Hannaea arcus (Ehr.) Patr.*	Ha	256,000	403,000,000
Diatoms	Chrysophyta	Diatomaceae	Meridion	*Meridion circulare (Grev.) Ag.*		82,300	52,200,000
Diatoms	Chrysophyta	Diatomaceae	Staurosira	*Staurosira construens var. venter (Ehr.) Hamilton*		27,000	2,410,000
Diatoms	Chrysophyta	Diatomaceae	Synedra	*Synedra rumpens Kütz.*		45,700	5,200,000
Diatoms	Chrysophyta	Diatomaceae	Synedra	*Synedra ulna (Nitz.) Ehr.*		18,300	112,000,000
Diatoms	Chrysophyta	Naviculaceae	Amphora	*Amphora pediculus (Kützing) Grun.*		18,300	1,920,000
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema minutum (Hilse in Rabenhorst) Mann*		27,400	5,030,000
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema silesiacum (Bleic. in Raben.) Mann*		27,400	17,400,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema angustatum (Kütz.) Rabh.*	Ga	146,000	58,800,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema minutum (Ag.) Ag.*		9,140	3,250,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema olivaceoides Hust.*		18,300	3,280,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema parvulum (Kütz.) Kütz.*		18,300	3,950,000
Diatoms	Chrysophyta	Naviculaceae	Luticola	*Luticola mutica (Kütz.) Mann*		18,300	11,800,000
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula gregaria Donk.*		54,800	15,600,000
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula pelliculosa Hilse*		9,140	244,000
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula viridula var. rostellata (Kütz.) Cl.*		9,140	8,130,000
Diatoms	Chrysophyta	Naviculaceae	Reimeria	*Reimeria sinuata (Greg.) Kociolek & Stoermer*	Rs	119,000	19,500,000
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia dissipata (Kütz.) Grun.*		18,300	4,650,000
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia microcephala Grun.*		9,140	993,000

Appendix 2. Periphytic algae data

[Abundance data for RTH and DTH samples is number of cells per square centimeter; biovolume data for RTH and DTH samples is cubic micrometers per square centimeter; abundance data for QMH samples indicates the presence of that organism]

Algae group	Phylum	Family	Genus	Lowest taxonomic level	Notation	Abundance	Biovolume
Costello Creek below Camp Creek near Colorado, (site number 96), Qualitative Multi-Habitat (QMH) Sample - August 3, 1999							
Diatoms	Chrysophyta	Achnanthaceae	Achnanthes	*Achnanthes biasolettiana (Kützing) Grunow*		1	
Diatoms	Chrysophyta	Achnanthaceae	Achnanthidium	*Achnanthidium minutissimum (Kützing) Czarnecki*		1	
Diatoms	Chrysophyta	Achnanthaceae	Cocconeis	*Cocconeis placentula var. lineata (Ehrenberg) Van Heurck*		1	
Diatoms	Chrysophyta	Achnanthaceae	Psammothidium	*Psammothidium bioretii (Germ.) Bukht. et Round*		1	
Diatoms	Chrysophyta	Diatomaceae	Diatoma	*Diatoma mesodon (Ehr.) Kütz.*		1	
Diatoms	Chrysophyta	Diatomaceae	Fragilaria	*Fragilaria vaucheriae (Kütz.) Peters.*		1	
Diatoms	Chrysophyta	Diatomaceae	Hannaea	*Hannaea arcus (Ehr.) Patr.*		1	
Diatoms	Chrysophyta	Diatomaceae	Meridion	*Meridion circulare (Grev.) Ag.*		1	
Diatoms	Chrysophyta	Diatomaceae	Synedra	*Synedra rumpens Kütz.*		1	
Diatoms	Chrysophyta	Diatomaceae	Synedra	*Synedra ulna (Nitz.) Ehr.*		1	
Diatoms	Chrysophyta	Diatomaceae	Tabellaria	*Tabellaria flocculosa (Roth) Kütz.*		1	
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema minutum (Hilse in Rabenhorst) Mann*		1	
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema silesiacum (Bleic. in Raben.) Mann*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema angustatum (Kütz.) Rabh.*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema minutum (Ag.) Ag.*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema olivaceoides Hust.*		1	
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema parvulum (Kütz.) Kütz.*		1	
Diatoms	Chrysophyta	Naviculaceae	Luticola	*Luticola mutica (Kutz.) Mann*		1	
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula cryptocephala Kütz.*		1	
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula cryptocephala var. veneta (Kütz.) Rabh.*		1	
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula gregaria Donk.*		1	
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula minima Grun.*		1	
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula radiosa var. tenella (Bréb. ex Kütz.) Grun.*		1	
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula viridula var. rostellata (Kütz.) Cl.*		1	
Diatoms	Chrysophyta	Naviculaceae	Reimeria	*Reimeria sinuata (Greg.) Kociolek & Stoermer*		1	
Diatoms	Chrysophyta	Naviculaceae	Sellaphora	*Sellaphora seminulum (Grun.) Mann*		1	
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia palea (Kütz.) W. Sm.*		1	
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia subtilis Grun.*		1	
Diatoms	Chrysophyta	unknown	undifferentiated	*undifferentiated diatoms*		1	
Diatoms	Chrysophyta	unknown	undifferentiated	*undifferentiated diatoms*		1	
Blue-green	Cyanophyta	Oscillatoriaceae	Lyngbya	*Lyngbya martensiana Menegh.*		1	
Blue-green	Cyanophyta	Oscillatoriaceae	Oscillatoria	*Oscillatoria formosa Bory*		1	
Euglenoids	Euglenophyta	Euglenaceae	Phacus	*Phacus pseudoswirenkoi Prescott*		1	
Green	Chlorophyta	Zygnemataceae	Mougeotia	*Mougeotia sp.*		1	
Red	Rhodophyta	Chantransiacea	Audouinella	*Audouinella violacea Kütz.*		1	

Appendix 2. Periphytic algae data

[Abundance data for RTH and DTH samples is number of cells per square centimeter; biovolume data for RTH and DTH samples is cubic micrometers per square centimeter; abundance data for QMH samples indicates the presence of that organism]

Algae group	Phylum	Family	Genus	Lowest taxonomic level	Notation	Abundance	Biovolume
Camp Creek at mouth near Colorado, (site number 95), Richest Targeted Habitat (RTH) Sample - August 4, 1999							
Diatoms	Chrysophyta	Achnanthaceae	Achnanthes	*Achnanthes biasolettiana (Kützing) Grunow*		224	27,700
Diatoms	Chrysophyta	Achnanthaceae	Achnanthes	*Achnanthes lanceolata var. haynaldii (Schaarschmidt) Cleve*		448	165,000
Diatoms	Chrysophyta	Achnanthaceae	Cocconeis	*Cocconeis placentula var. lineata (Ehrenberg) Van Heurck*		224	226,000
Diatoms	Chrysophyta	Diatomaceae	Fragilaria	*Fragilaria vaucheriae (Kütz.) Peters.*		1,340	266,000
Diatoms	Chrysophyta	Diatomaceae	Hannaea	*Hannaea arcus (Ehr.) Patr.*		448	704,000
Diatoms	Chrysophyta	Diatomaceae	Meridion	*Meridion circulare (Grev.) Ag.*		224	142,000
Diatoms	Chrysophyta	Diatomaceae	Synedra	*Synedra rumpens Kütz.*		112	12,700
Diatoms	Chrysophyta	Diatomaceae	Synedra	*Synedra ulna (Nitz.) Ehr.*		1,570	9,590,000
Diatoms	Chrysophyta	Diatomaceae	Tabellaria	*Tabellaria flocculosa (Roth) Kütz.*	Tf	4,030	1,440,000
Diatoms	Chrysophyta	Epithemiaceae	Epithemia	*Epithemia turgida (Ehr.) Kütz.*	Et	2,350	25,000,000
Diatoms	Chrysophyta	Naviculaceae	Amphora	*Amphora pediculus (K¸tzing) Grun.*		896	94,000
Diatoms	Chrysophyta	Naviculaceae	Cymbella	*Cymbella cistula (Ehr.) Kirchn.*		224	270,000
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema lunatum (Smith) V. H.*		224	415,000
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema silesiacum (Bleic. in Raben.) Mann*		224	142,000
Diatoms	Chrysophyta	Naviculaceae	Encyonema	*Encyonema minutum (Hilse in Rabenhorst) Mann*		896	164,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema minutum (Ag.) Ag.*		448	159,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema angustatum (Kütz.) Rabh.*		448	180,000
Diatoms	Chrysophyta	Naviculaceae	Gomphonema	*Gomphonema olivaceum (Lyngb.) Kütz.*		224	83,000
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula radiosa Kütz.*		448	497,000
Diatoms	Chrysophyta	Naviculaceae	Navicula	*Navicula radiosa var. tenella (Bréb. ex Kütz.) Grun.*		224	45,700
Diatoms	Chrysophyta	Naviculaceae	Reimeria	*Reimeria sinuata (Greg.) Kociolek & Stoermer*	Rs	3,140	515,000
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia inconspicua Grun.*		224	8,000
Diatoms	Chrysophyta	Nitzschiaceae	Nitzschia	*Nitzschia perminuta (Grun.) Peragallo*		224	34,000
Diatoms	Chrysophyta	Thalassiosiraceae	Cyclotella	*Cyclotella meneghiniana Kützing*		112	82,000
Blue-green	Cyanophyta	Nostocaceae	Amphithrix	*Amphithrix janthina (Mont.) Born. and Flah.*		23,200	292,000
Blue-green	Cyanophyta	Nostocaceae	Anabaena	*Anabaena sp.*		3,280	272,000
Blue-green	Cyanophyta	Oscillatoriaceae	Lyngbya	*Lyngbya sp.*		16,100	2,240,000
Green	Chlorophyta	Zygnemataceae	Mougeotia	*Mougeotia sp.*		6,060	31,100,000
Red	Rhodophyta	Chantransiacea	Audouinella	*Audouinella violacea Kütz.*		74,700	453,000,000